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Environmental Justice: Investigating the Past, Present, and Future of Lead in Drinking Water

by

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Abstract

This thesis aims to look at the impact of lead usage in water systems across the US to examine the inequities experienced by disadvantaged communities using an environmental justice lens. Lead contamination of water has been a large source of environmental distress to communities across the world. In recent years, the negative impacts of lead in drinking water have come to the forefront due to events such as the Flint Water Crisis, resulting in the uncovering of widespread lead pipe usage in cities across the United States. Risk of water lead contamination, however, does not affect everyone in the same way, and in fact has been seen to disproportionately impact disadvantaged communities. The effects of lead water contamination have long been studied, but little work focuses specifically on the environmental justice roots of today's lead pipe usage. This study conducts a three-pronged analysis in order to investigate the past, present, and future of the situation: (1) a data analysis of lead service line mappings with historical redlining data, (2) research into the correlation between current household demographics and lead pipe presence, and (3) a meta-analysis to study remediation efforts across cities and discern patterns between neighborhoods of priority. The results vary between each city analyzed, but the findings largely show that the HOLC grade of the neighborhood a house is found in has an impact on the likelihood of having lead pipes. Similarly, results show that demographic traits such as race, income, age, employment status, educational attainment, citizenship, and language spoken in the household have a significant impact on the likelihood of lead pipe presence, though the way in which each impacts the likelihood varies between the cities analyzed. Lastly, this study highlights the common aim of remediation efforts to focus on those with the greatest lead exposure, however, the efficacy of this endeavor is often not fully confirmed. Overall, these results provide greater knowledge of at-risk populations for lead exposure from an infrastructure perspective, which can aid in developing appropriate responses to current and future water crises.

Contents

Introduction

On April 25th, 2014, the over 100,000 constituents of Flint, Michigan turned on their faucets to find water from the Flint River pouring out. In an effort to reduce spending and save money, the Flint city government had made the decision to switch their water supply from the Huron River to the Flint River. Due to lack of necessary corrosion control treatments, however, the water from the Flint River quickly corroded the lead pipes found across the city. As a result, lead soon seeped into the city's drinking water, making it unsafe for the Flint constituents to consume, per EPA regulations (Masten, Davies, and McElmurry, 2016). This crisis brought national attention to the city in Michigan, with many shocked that a state known for its five Great Lakes, invaluable sources of fresh water, was home to a city that had some of the worst water quality in the nation. The Flint Water Crisis (FWC) was an egregious example of the consequences of letting lead contamination go unchecked in drinking water, but it was also the catalyst for greater recognition of the nation's deteriorating infrastructure that had the potential to wreak havoc on cities across the U.S. if the water systems were not properly maintained. As President Biden said when announcing the American Jobs Plan, "There's hundreds of Flints all across America."

The aftermath of the lead contamination in Flint makes it clear that the FWC is an environmental, political, and socio-economic issue. Countless studies have investigated the impact of the FWC on fertility (Grossman and Slusky, 2019), maternal health (Wang, Chen, and Li, 2021), education (Trejo et al, 2020), child intelligence (Sauve-Syed, 2018), and the economy (Christensen, Keiser, Lade, 2019). The Flint water crisis provided many researchers with what is considered to be a "natural experiment" for a variety of topics. One key factor that many of the studies have in common is that the negative consequences have disproportionately impacted different groups of people, namely discriminating on race and income (Muhammad et al., 2018; Demashkieh et al., 2017).

At its core, however, the FWC was an infrastructure issue. Lead contamination of water is at its roots due to lead pipes. Though lead plumbing was banned by the federal government in 1986, many communities still have lead service lines, built before the regulation change (Brown and Margolis, 2012). Without the proper treatment of water, these pipes begin to corrode and eventually the metal enters the water. Our country faces extreme infrastructure inequity, and as a result, many lead water contamination crises are rooted in cities that house disadvantaged communities. Flint is a predominantly Black city, with low wealth overall. In 2016, Newark, New Jersey, received national attention when it faced its own lead water contamination crisis (Dave and Yang, 2020). Newark is one of the poorest cities in New Jersey and in the U.S. and is also a majority-Black city. Today, less than 6 years after the FWC, Benton Harbor, Michigan, another city with a majority Black population, is facing a lead water contamination crisis of its own, and despite calling for government action for over two years now, the same state that failed Flint is failing Benton Harbor (Lutz and McCormick, 2021).

Lead contamination is a difficult problem because when a water test indicates elevated levels of lead, it is already too late. The best way to anticipate potential future lead contamination in water is by inspecting the pipes, but this can be a costly endeavor for a city to undertake (McWhirter and Maher, 2016). Thus, time and time again we are learning about new cities that are not at the beginning of a crisis, but right at the midst of one. When compounded with that fact that public response is failing to target the problem and develop solutions efficiently and effectively, inequity is given the perfect environment to flourish. This thesis, thus, choses to focus not on where elevated blood lead levels are being found, but rather on where lead pipes are being used.

Today, environmental risk remains unevenly distributed between communities, with risks affecting populations in different ways (Wodtke, Ramaj and Schachner, 2020). Environmental justice is an area of study that is focused on addressing that disproportionately high and adverse effects of environmental hazards faced by low-income and minority communities. Though a flourishing research area, environmental justice research has failed to expand conceptually and geographically in the same way other areas of focus have, resulting in a deficiency of research in the space (Reed and George, 2011). Subsequently, this thesis hopes to contribute towards the current lacking discourse on environmental justice. Given the long history of lead exposure in the U.S., lead poisoning truly is the longest-lasting childhood health epidemic in the nation, though it has never been regarded as such due to conflicts around politics, class, and race (Rosner and Markowitz, 2013). While environmental justice extends far beyond just water quality, the current crisis that the United States is facing provides an ideal anchor subject in developing a greater understanding of environmental justice in the country. Though studies have begun to investigate the effect of lead exposure on disadvantaged communities, few have focused specifically on lead service line infrastructure as a main culprit of the health epidemic.

Statement of the Problem

The disadvantages that disadvantaged communities face today are not simply due to current actions but can also be largely attributed to past actions and structures that perpetuate inequality. Namely, the current environmental injustice in our country cannot be ignored, and thus this thesis uses lead contamination of water to provide insight into this plight. Federal policy has failed in alleviating impoverished and marginalized communities from poor infrastructure, thus depriving children of equal opportunity and trapping generations in poverty (Benfer, 2017; Coates, 2014). In the same vein, the decisions that city governments chose to make today can have a lasting effect on the direction of the future.

The objective of this thesis is to analyze the past actions, present events, and future decisions that are being made with respect to lead contamination of drinking water. Specifically, a better understanding on the usage of lead in water systems will inform about the disproportionate impact on disadvantaged groups. Data will be analyzed across three cities that experienced lead water contamination crises using a framing theory to effectively understand all facets of the situation. This framing theory is led by three research questions:

1. *Past:* What is the correlation between the presence of lead plumbing today and historical redlining?
2. *Present:* How are household demographics correlated with lead pipe presence?
3. *Future:* How are remediation efforts being conducted and what factors determine areas of priority?

The first question will focus on the past, examining the lead plumbing landscape in the context of historical redlining data. This data comparison will allow for a better understanding of the cyclical disadvantages that disadvantaged communities are facing today, due to past mistakes. This overlay of lead plumbing and historical redlining is something that has yet, to my knowledge, been done, making this a novel approach that will add a new dimension to the understanding of the history and implications of environmental justice.

Looking deeper into the current demographic breakdown of the households in lead contaminated cities will allow for a comparison of the progression of equity over the years. The second question aims to focus on the present situation of environmental justice. By analyzing current census data within the context of the lead pipe usage data, a deeper understanding of the current makeup of the population that is most at risk to experience lead water contamination will be developed. There has yet to be in-depth analysis conducted on lead service line data on a household-level, and this study aims to uncover certain trends common among the households with the greatest probability of having lead contamination.

The last research question allows for a more forward-looking understanding of environmental justice. Specifically, the public and government response to the crises set up the foundation for the attitudes of the future. An analysis of each cities' approach to remediation efforts will allow for a side-by-side comparison to view best practices. In each city, remediation efforts began somewhere specific, with specific areas of initial priority. This study will supplement meta-analysis of remediation efforts with spatial mappings showcasing different traits about those areas of priority, to uncover common traits among the focus neighborhoods. Though residents have repeatedly complained about their governments' lacking responses to their respective water crisis, not much attention has been given to conducting an in-depth analysis of government response, and no study has yet to focus specifically on the first location of remediation work within these cities.

Justification of the Problem

The motivation for this thesis stems from the perspective that working with communities to solve local problems can often result in making an impact globally. This thesis is just one piece of the larger puzzle on global environmental justice. Lead water contamination is a global problem, with awareness of the impact of exposure growing in developing countries, and the resulting public health issues disproportionately affecting minority and socioeconomically disadvantaged groups (Tongl, von Schirnding, and Prapamontol, 1999; Biswas, Sachdeva, and

Tortajad, 2021). Environmental justice is an important topic around the world and working on improving it in our own backyards will allow us to better help others down the line (Chaudhuri, 1998).

With new data outlining the presence of lead pipes on a household basis in cities across the US, there is an opportunity to conduct novel research on the specific impact of historical decisions and current demographics on lead exposure at a granular level. To truly improve our society, attention and care must be given to the roots of the problems, in order to prevent cycles of poverty and injustice. An in-depth analysis looking at lead plumbing specifically has the potential to lead to greater knowledge of at-risk populations for lead exposure from an infrastructure perspective. Establishing this strong foundational understanding will help to develop more appropriate responses to current and future water crises.

This thesis continues with the following sections. Background information is provided on the health effects of lead exposure, lead contamination of drinking water, the Flint Water Crisis, and the landscape of inequity in the U.S. A literature review is conducted that details studies that have resulted from lead exposure and water contamination across the United States and provides context to the lead exposure experienced by disadvantaged communities. Following this, the theoretical framework is described, with an overview of the environmental justice lens and a description of hypotheses. This thesis focuses on each of the three research questions individually, with an outline of the respective methodology, results, and discussion. This thesis ends with a general discussion as well as a dialogue on the studies limitations as well as future areas of research.

Background

Lead Exposure

Lead is one of the most common elements found in our daily lives, naturally occurring in the earth's crust and widely used in batteries, gasoline, pigments, weights, and ceramics, among other things. Though useful due to its strength, malleability, and durability, lead can be very dangerous when ingested. As a developmental neurotoxin, exposure to lead has adverse effects, especially when it is found in children and pregnant women (EPA, 2021). **Appendix I** presents a diagram outlining the health effects of lead exposure on both adults and children.

Once ingested, lead quickly enters the blood stream and can harm one's health. Blood lead levels rise immediately after ingestion and lead is stored in the bone. Though your body can release lead through sweat, urine, and feces, it can take decades for the lead in bones to decrease (CDC, 2021). From bone, lead is excreted slowly over time back into the blood, and though only about 1 percent of lead in the body is found in the blood, these traces of lead can have disastrous effects on many organ systems, primarily the brain (Martin and Acs, 2018).

Studies have linked the negative consequence of lead exposure in children as early as 1956 (Chisholm and Harrison, 1956). The Center for Disease Controls clearly states that there is no safe blood lead level for children (CDC, 2021). Brain and nervous system damage, learning and behavior problems, hearing and speech difficulties and slowed growth and development have all been well-documented as adverse effects to lead exposure in children (Goldstein, 1992). When lead is found in children, studies have shown that there can be negative effects on the child's intelligence, attention span, and performance in school (Magzamen et al., 2013; Amato et. al., 2012). Children are more likely to be impulsive, hyperactive, depressed, withdrawn, and anxious. Additionally, long-term harm has been studied and results have shown that the harm on the body during critical stages of neurological development due to lead have been proven to result in increased criminal convictions and teen pregnancy, decreased educational achievement, and even a decline in IQ and socioeconomic status in adulthood (Martin and Acs, 2018; Reuben et al., 2017). The difficulty of the situation often falls on the fact that lead exposure is difficult to see, since most children present no obvious symptoms.

When a pregnant woman is exposed to lead, the lead can be passed onto her fetus (Al-Saleh et al., 2011). Not only can the baby be born with elevated blood lead levels, leading to all the aforementioned consequences, but too much lead in the body during pregnancy can cause its own slew of problems. Specifically, elevated blood lead levels can put pregnant women at risk for miscarriage and premature birth and can put babies at risk of being small for gestational age and for brain, kidney, or nervous system damage (Nowicki and Gomez, 2018; Grossman and Slusky, 2019). Research has shown that these negative birth outcomes are worse for those children born to Black mothers (Wang, Chen, and Li, 2021). Babies can also be exposed to lead through breastfeeding and through formula prepared with lead contaminated water, often due to pipe corrosion (CDC, 2021).

Lead-based paint has been one of the most common sources of lead exposure for decades. Up until 1978, lead paint was allowed to be uses in homes. After numerous studies identified lead paint as being a huge culprit towards elevated blood lead levels, the use of lead in paint was banned. However, due to decades of campaigns by the Lead Industries Association (**Appendix II)**, misinformation about the safety of lead paint remained widespread, and though new paint no longer contains lead, many homes still have traces of lead paint that predate the ban (Markowitz and Rosner, 2000). Studies have found that children living in less educated households and children living in houses built before this cut-off are more likely to encounter lead around their homes and are thus at greater risk of lead exposure (Lanphear et al., 1997). This has resulted in a disproportionate amount elevated blood lead levels being found in children from low-income households and marginalized communities of color, whose homes constitute the majority of those left with lead hazards (Benfer, 2017; Moody, Darden, and Pigozzi, 2015; Pirkle et al., 1998).

Even if a child is in a lead-free household, children can still be exposed to lead if others in their family bring lead home with them. This is most common when adults work in industries related to lead, such as battery manufacturing or home repair, leading lead dust to be found in their hair, on their skin, and stuck to their clothes. This lead dust can spread around a house, sticking to carpets, floors, and furniture that a child can touch and may accidentally ingest (CDC, 2021).

Governments and authorities have done their best to eliminate the sources of lead from our daily lives, given the hazardous consequence of lead exposure. However, lead is still finding a way to seep into the bodies of many across the US due to outdated infrastructure, and one of the main ways today is through lead contamination of drinking water (Bellinger, 2016).

Lead Contamination of Drinking Water

Today, the EPA predicts that 20 percent of total lead exposure for adults and 40 to 60 percent of total lead exposure for children comes from drinking water (EPA, 2021). It is estimated that as much as 75 percent of lead found in drinking water is a result of the use of lead service lines (Sandvig et al., 2008). It was common for lead pipes to be used in city water systems due to the durability of the material before it was uncovered that this could result in water contamination when water is left untreated for corrosion prevention. In 1986, the use of lead in plumbing was banned by the federal government, however, similar to lead paint, lead pipes still make up a large part of the nation's infrastructure, as most plumbing systems predate the federal ban (Brown and Margolis 2012). In 2016, nearly a third of community water systems in the United States reported the usage of lead in some of their service lines (Cornwell, Brown and Via, 2016).

This infrastructure is cause for concern, because when adequate care is not given to these lead pipes, lead is able to seep into the water supply. An informed treatment to control corrosion must be implemented; essentially, coating the inside of the lead pipes to prevent the lead from corroding and entering the drinking water (Smith, 2015). When authorities stop treating the water effectively, the built-up inner coating of the pipes begins to wear away, and when harsh water begins to flow through the pipes, lead particles enter the water stream. Once in the water stream, lead is able to readily be ingested and blood lead levels begin to rise immediately. Left unchecked, this can have detrimental effects on the health of a community. In the aftermath of the FWC, the director of the Office of Groundwater and Drinking Water released a memo asserting the requirement for large systems to have corrosion control treatments (Grevatt, 2015). By simply having lead pipes, however, communities across the country already have the building blocks for a potentially catastrophic health crisis.

Given the widespread presence of lead service lines, with an estimated 10 million lead service lines in the ground across the country today, it becomes clear that the FWC is less of an anomaly than it was originally conceived to be (Wisely and Spangler, 2016). Though the FWC saw elevated blood lead levels like never before seen, the public attention given to Flint has resulted in many looking to their own towns, with large cities like Newark, Toledo, Detroit, Chicago, and New York City uncovering water crises of their own due to lead contamination (Dave and Yang, 2020; Maslin Nir, 2018; Demirchyan, 2019; Maher 2018).

Per the EPA's Lead and Copper Rule, steps must be taken to treat water systems where 10% of the water exceeds the lead action level of 15 parts per billion (ppb) (EPA, 2008). This is a generous threshold, given this rule allows up to 20 ppb of lead in drinking water even though it has been proven that there is no safe amount of lead exposure for children. Even with this seemingly lenient regulation, in 2018, drinking water for nearly 30 million people across the country came from water systems that violated the threshold (Hamp, Zimmerman, and Hoffen, 2018). More recently, from the start of 2018 to the end of 2020, 186 million people in the U.S. were reported to receive drinking water from systems with lead levels exceeding 1 ppb; this is over half of the country's population (Fedinick, 2021). Revisions of the EPA's Lead and Copper Rule in 2021 aim to establish a trigger level to jumpstart mitigation earlier and in more communities (EPA, 2021).

Lead contamination of drinking water is a difficult and expensive problem to fix. The problem needs to be solved at its root, which normally entails digging up and replacing the lead pipes (Bellinger, 2016). Such a task at a national scale is estimated to cost tens of billions of dollars, and that is without taking into account that added complexity of needing to determine where these pipes are buried (McWhirter and Maher, 2016). Cities have been struggling to identify the location of their lead service lines due to the antiquated record keeping methods that are common for plumbing; namely, the use of manila-colored index cards (Wisely and Spranger, 2016; Chojnacki et al., 2017; **Appendix III**).

Drinking water can quickly become contaminated with lead when corrosion control treatments fail to maintain the purity of the water. The abundance of lead service lines due to outdated infrastructure is the largest culprit for this hazard, and ultimately, the use of lead pipes is most common in older homes, and as a result disproportionately affects children in lower-income households (Martin and Acs, 2018). This presents a necessary question about the status of environmental justice in our country from the perspective of lead service lines, and this thesis attempts to begin to answer that question.

Flint Water Crisis

Though this thesis extends beyond just the city of Flint, the FWC is often seen as the "whistleblower" event due to it being one of the first high-profile city water crises, even garnering attention from the President (McWhirter and Maher, 2016). The FWC was in many ways a worst-case scenario, though it is not a complete anomaly (Hobbs, 2018). For this reason, it's important to have a clear background on the FWC. The FWC was a large catalyst for this thesis, and many similarities can be found between the FWC and other water crises that this thesis reviews.

An in-depth description of the FWC can be found in **Appendix IV**, followed by a visual chronological timeline of the events in **Appendix V. Appendix VI** shows a mapping of lead contamination of water samples across the city of Flint from the first samples drawn in 2015.

Lead Service Lines

In 2016, long after the FWC had captured the attention of the nation and the President had declared a state of emergency, the city of Flint still had very little idea where their lead service lines actually were. Due to the antiquated methods of collection, mainly using handwritten notecards from when the water system was originally implemented, the Flint government wasn't entirely sure where to begin their projects. They turned to a team of researchers who developed a data science approach to map the probabilities of lead contamination across the city (Chojnacki et al., 2017). The product of this work was a tech start-up called BlueConduit, which works with city governments to help identify lead water service lines. Since developing a Flint service line map, BlueConduit has worked with more than 50 municipalities, mapping nearly 1 million service lines, including the service lines in Toledo, OH, Trenton, NJ, Detroit, MI, and Benton Harbor, MI (Robinson, 2021).

Similar efforts have been seen across the country. Other cities with lead service line mappings include Naperville, IL, Cleveland, OH, Newark, NJ, Washington DC, and New York City, NY. These efforts to develop accurate mappings of lead water service lines provide the necessary data to be able to conduct analysis on lead service line presence.

This thesis will focus on data on the presence of lead service lines rather than lead water contamination levels. Not only does this allow for a novel research approach, but it also reduced cross-data set differences regarding the threshold level used for what constitutes as lead water contamination are minimized. There are four different common thresholds used among data related to lead water contamination: the EPA's standard of 15 ppb, the FDA's threshold of 5ppb for bottled water, the American Academy of Pediatrics' (AAP) threshold of 1ppb, or the CDC's threshold that there is no safe level of lead in drinking water. Focusing on physical lead existence, rather than what a city or data portal considers to be elevate lead in the drinking, will allow for a more streamlined data approach and less sources of error. Additionally, the focus on the infrastructure behind this contamination, rather than the contamination itself, lends itself to aligning more closely with the environmental justice perspective.

The Landscape of Inequity in the U.S.

As has become apparent, lead contamination of drinking water is an environmental justice problem. Due to the societal inequities in infrastructure, the negative effects of lead exposure are repeatedly being found disproportionately among disadvantaged communities. To understand this, it's important to have some context of the racial history found in cities across the country. Specifically, looking back to the Civil Rights Movement of the 1950s and 60s, the phenomenon of "white flight" pops up across the map (Frey, 1980). As Black people began to flock cities postwar, it was common for white residents to leave the city centers. This new Black resident population had economic and structural effects on cities, and as cities experienced more "white flight", city wealth decreased. This resulted in poor maintenance of much city infrastructure, including lead plumbing and water systems. Flint, Michigan is a prime example of this situation, having been a flourishing city as the home of General Motors until experiencing an enormous demographic shift in the 1960s, resulting in the city becoming majority-Black while struggling to maintain its aging water system. Cities that are majority-Black today often report experiencing higher rates of poverty and unemployment, in consequence (Stone and Stoker, 2015). It is important to note that this is not simply a result of decreased income, as racial stratification can commonly result in the average lower-income White resident living in better conditions that affluent Black residents (Sampson and Winter, 2016). Due to the poorer and older conditions of infrastructure in disadvantaged neighborhoods, residents are exposed to health hazards at disproportionately high levels (Massey, 2004). As a result, race can often be seen as a predictor of environmental and public health.

The failure of federal policy in alleviating impoverished and marginalized communities of color from their poor infrastructure has resulted in depriving children of equal opportunity and trapping generations in poverty. Specifically, federally assisted housing, which still today houses people in units built before 1978, has been found to perpetuate health inequities and increase socioeconomic and racial inequality among low-income and minority children (Benfer, 2017). Racist housing policies continue to exacerbate this divide as the government continues to pull money out of urban city projects and housing projects for majority Black populations (Coates, 2014).

Literature Review

The literature review that follows will focus on previous studies that have been conducted surrounding lead contamination of water. Before diving into each study of this thesis, additional context will be given that correlates with each research question of focus.

Impact of Lead Contamination of Water on Education

Lead exposure can have severe short-term and long-term effects on children. With the disastrous neurological effects on children, including the development of behavior problems, psychological effects, and decreases to sensory and motor function, identifying lead in child settings is crucial (Martin and Acs, 2018). Over 50 million children rely on their schools as their daily source of water, thus, schools need to make sure that they are ensuring that their water sources are clean of lead contaminants (Nowicki and Gomez, 2018). This has stimulated a wide array of studies conducted in schools to develop an understand the impact of presence of lead in drinking water on education.

Lead has been found in drinking water in school across the U.S. in recent years. In 2018, Colorado and Florida began taking steps to decrease the lead in their drinking water with some cities conducting their first even water testing in the schools, Indiana found that 61% of schools have one or more fixtures with elevated lead levels, and Maryland updated its laws resulting in districts having to replace hundreds of fixtures (Maher, 2018). In August 2018, the city of Detroit completely shut off the drinking water across the school district right before the beginning of the academic year out of concerns of elevated lead levels in multiple buildings, the city ultimately identifying 57 of the 86 schools checked as having lead or copper levels above the EPA threshold (Maslin Nir, 2018). Students at these schools had to depend on provided water bottles and ultimately relied on coolers for months (Hobbs, 2018). Around the same time, it was reported that in New York City, over 1,100 water fixtures had lead levels above the threshold (Shapiro, 2018). The U.S. Government Accountability Office published a report in July of 2018, showing that 43% of the surveyed school districts had tested for lead in 2016 or 2017, and that of those, 37% showed elevated lead in the drinking water, with about 41% of school districts stating that they hadn’t tested for lead in the 12 months before completing the survey, and 16% saying that they didn’t know if they had ever tested (Nowicki and Gomez, 2018).

Not only is lead contamination rampant in the water sources of school across the country, but the lead contamination can result in multiple adverse effects on the education and academic achievement of students. Firstly, the stress that comes with the fear of lead contamination is bounded to have negative psychological effects on students, due to the uncertainty of food and water security and the disruption of routines with school closings (McWhirter and Maher, 2016). The effect of lead on the nervous system of children can both decrease academic performance and IQ due to decrements in cognitive function (Martin and Acs, 2018). Additionally, lead exposure in elementary schools in Milwaukee and Racine, Wisconsin was shown to result in students exhibiting a significantly lower performance compared to those students not exposed to lead, though noise due to differences household socioeconomic status must be considered as well (Magzamen et al., 2013; Amato et al., 2012). This is supported by research on the impact of sustained exposure to a disadvantaged neighborhood with a high level of lead contamination in child development, producing results which show a reduction in receptive vocabulary ability by two-fifths of a standard deviation (Wodkte, Ramaj, Schachner, 2020). An in-depth study conducted on the Chicago Public School System investigated the intersection between lead contamination of water, school quality, race, and income, and found that almost all of the schools that showed elevated levels of lead had a majority of low-income students and students of color (Demirchyan, 2019).

Impact of Lead Contamination of Water on Child Outcomes

When children are exposed to lead, many health issues arise. A few of those issues can continue into adulthood, and thus a growing body of work has begun to surround outcomes for children exposure to lead. One such topic of interest is the study of the behavioral and psychological wellbeing of children who are exposed to lead, with results finding that due to the harm at critical stages of neurological development, lead exposure can affect children into their adulthood, with recorded increased incarceration rates, unintended pregnancies, and academic struggles (Martin and Acs, 2018). Further studies have expanded this connection between childhood lead exposure and adulthood changes in IQ to also identify a decrease in socioeconomic mobility as adults (Reuben et al., 2017).

Research has shown that the differences in exposure to environmental health hazards can act as conduits for neighborhood poverty to harm early cognitive development, specifically in the context of lead contamination (Wodtke, Ramaj, Schachner, 2020). Curiously, a large-scale study was conducted across the U.S. and Europe and found that exposure to lead in childhood had an impact on adult personality, with those who grew up in areas with greater lead exposure being less agreeable and conscientious, and more neurotic (Schwaba et al., 2021). Though eye-opening and informative, the body of literature on child outcomes is time intensive, as much of the awareness about lead contamination is still recent, and as such, with many recent lead water contamination crises arising, many studies on the long-term effects into adulthood are still in process.

Impact of Lead Contamination of Water on Fertility and Birth Outcomes

Though lead exposure is most commonly thought about in the context of child neurological development, exposure to lead has also been seen to have large adverse effects on pregnant women. Pregnant women who are exposed to lead are at a greater risk for miscarriage, stillbirth premature birth, fetus organ damage, and low body weight (CDC, 2021; Nowicki and Gomez, 2018). Lead can be transferred from their mother's blood streams to fetuses during fetal development and to newborns via breastfeeding (Al-Saleh et al., 2011).

The Flint Water Crisis led to a variety of studies on fertility and birth outcomes. Comparing the fertility rates and health at birth in Flint before and after the water source switch showed that once mothers were exposed to lead, fertility rates decreased by 12% and overall health at birth decreased due to negative selection of healthy embryos and fetuses not surviving, and due to scarring of those fetuses that did survive, with a selection scarring effect of 5.4% decrease in birth weight (Grossman and Slusky, 2019). Studying the effect of utero exposure showed that water lead contamination caused the rate of low birth weight to increase by 15.5%, with a 19% increase in rate of low birth rate among children born to Black mothers (Wang, Chen, Li, 2021).

As cities across the U.S. discovered their own hidden infrastructure disasters and focused their attentions on ensuring safe drinking water due to Flint raising awareness of the toxic traits of lead, Newark, New Jersey began to make headlines. Unlike Flint, where the entire city became susceptible to lead contamination of drinking water, the Newark Water Crisis saw two completely different sides of the coins due to two treatment plants, one of which experienced elevated lead levels in their drinking water due to the decision to increase the acidity of the treated water. Within the same city, different people had access to safe and contaminated tap water, thus providing the perfect environment for an in-depth study on birth outcomes. By comparing the birth outcomes of pregnant women with treatment from both plants, the study was able to find that the lead exposure significantly raised the chance of low birth weight or preterm births by approximately 14 to 22 percent, with these negative effects largely found among mothers of lower socioeconomic status (Dave and Yang, 2020).

Impact of Lead Contamination of Water on Economics

Not much research has shown the economic effects of water lead contamination. Notably, after the Flint water crisis, a team of researchers studied the impact of the water crisis on the housing market in Flint, finding a decrease in the value of the housing stock by $480 million, despite the government’s $400 million effort to remediate the situation (Christensen, Keiser, Lade, 2019). With the Flint home prices remaining lower than normal for 16 months after the all-clear was given on consuming the Flint water, this study is a clear indication of the negative long-term effects that result from water lead contamination.

Lead Exposure Within Disadvantaged Communities

For decades, research has shown that race and income level are both directly correlated to a child’s lead exposure (Lanphear, Weitzman, and Eberly, 1996). Many key predictors of elevated blood lead levels are sociodemographic factors such as Black race and low income (Hanchette, 2007). Throughout the U.S., elevated blood lead levels in children have been associated with neighborhood poverty (Griffith et al., 1998; Gleason, Nanavaty, and Fagliano, 2019). For children living in homes built before 1946, studies estimate that high blood lead levels were found among 21.9% of Black children and 16.4% children in low-income families (Pirkle et al., 1998). The discussion about the racial foundation of lead poisoning at a neighborhood level is one that is just beginning to build speed. Recent studies have begun to analyze the magnitude of lead poisoning in minority communities, exploring whether the decline in lead rates is experienced evenly across white and Black communities (Turner, 2016). Research on Chicago Public Schools supports these results, as evidence is found between the race, presence of lead, and quality of school (Demirchyan, 2019).

Studies into urban children have only highlighted the strong impact that race and income have on water lead contamination outcomes. Central-city neighborhoods are typically closer to lead emission sources, have older housing, and are also commonly racially segregated with a high proportion of Black children and low-income households. It was found that predictors of higher-than-average blood lead levels were Black segregated neighborhoods with lower socioeconomic characteristics, and, while increasing levels of socioeconomic characteristics heightened the divide, after arranging children by age, the Black-white racial gap in blood lead levels was nullified for those children living in the same neighborhoods of the lowest socioeconomic status (Moody, Darden, and Pigozzi, 2015).

Across the U.S., the disparities in environmental health highlight the cyclical nature of poverty in the U.S. Though the U.S. is built on the idea of the American dream, injustices such as those due to environmental practices and infrastructure eliminate the opportunity for upward mobility for disadvantaged groups (Moore, 2012). Instead, the legacy of racial inequality is maintained through environmental injustice (Sampson and Winter, 2016). Not only are minority individuals more exposed to lead, but the health outcomes are seen to be more harmful to individuals from minority communities. For example, birth outcomes among women exposed to lead are found to be significantly worse among children born from Black mothers (Wang, Chen, and Li, 2021). A city's Black residents are found to bear the burden of the lead contamination, experiencing cumulative damage (Sampson and Winter, 2016). Improvements on water lead contamination, therefore, have the ability to potentially reduce economic and social inequality (Martin and Acs, 2018).

A recent study published in the International Journal of Environmental Research and Public Health produced results that indicated that the social condition of being African American produced a larger risk for lead exposure that living in an old house. The same study showed Black children living below the poverty line to be twice as likely to have elevated blood lead levels than poor white or Hispanic children (Yeter, Banks, and Aschner, 2020). As Whitehead and Buchanan put it in their 2019 study, “lead exposure is not equal for all children—low-income and minority children continue to bear a disproportionate burden of exposure primarily through contact with deteriorating lead-based paint from older housing and potentially through drinking contaminated water resulting from failing leaded pipes,” (Whitehead and Buchanan, 2019).

Given the amount of research on the subject, it is no longer a question that lead poisoning disproportionately affects disadvantage communities. This thesis aims to further explore that fact by analyzing the presence of lead pipes across demographics, which result in these disproportionate health problems.

Theoretical Framework

Environmental Justice

The environmental justice frame is one that is very important to understand in the context of this thesis, given the goal to contribute to this growing body of work. Environmental health hazards are unevenly distributed among communities, with disadvantaged communities often experiencing disproportionately negative effects. As cities develop, the government must make decisions about where to place harmful yet necessary infrastructure, including highways, landfills, and highways. The result is that most governments chose the "path of least political resistance", which often results in selecting sites in communities that are less well-equipped with opposing the decision, or, in other words, less affluent communities and communities of color (Elliott and Frickel, 2013). As a result, disadvantaged communities face unfavorable housing stock, with older and abandoned structures being the norm, among which exposures to environmental hazards, such as harmful materials used in their construction, is common (Mohai, Pellow, and Roberts, 2009; Muller, Sampson, and Winter, 2018).

In 1994, President Clinton released an executive order requiring every federal agency to improve the health and environment effects of that agency's programs targeting minority and low-income populations (Cutter, 1995). However, this effort did not produce much tangible change, and environmental risk remains unevenly distributed still today, with risks affecting populations in different ways (Wodtke, Ramaj and Schachner, 2020). This presents itself in many ways. For example, research has shown that when compared to areas with over 40% minority residents, areas where residents are majority white have 11 times more green space (Vidal, 2010).

Though not regarded as such due to politics, class, and race issues, lead poisoning is the longest-lasting childhood health epidemic in the nation (Rosner and Markowitz, 2013). Very early on, the hazards of lead-poisoning were quickly categorized as problems for the poor, city officials even arguing that the epidemic would disappear once slums were eradicated (Bowditch, 1957). However, the problem clearly persists today. Research from over two decades ago already asserted that intervention strategies for lead poisoning should focus on old and poor neighborhoods, and those with minority groups, due to the inequities in housing quality and maintenance practices (Griffith, Wheeler, and Johnson, 1998). Adopting an environmental justice frame in my thesis will allow better mobilization for social change (Capek, 2014). The term environmental justice often brings ambiguity due to the young body of work that supports it. My thesis aims to be a step in a new direction, bringing more quantitative data to the world of environmental justice, with a focus that has not yet been explored.

General Hypothesis

I divide my hypotheses about the results of my data analysis among the three research questions of my thesis that will constitute three different studies.

1. *What is the correlation between the presence of lead plumbing today and historical redlining?*

    I believe that there is a strong correlation between lead plumbing and historical redlining. Historical redlining still plays a role in the demographic divide today (Stone and Stoker, 2015; Sampson and Winter, 2016). Historical redlining is likely to overlap with those places that have poorer and older infrastructure, and thus residents there are likely to be exposed to lead at high levels. Thus, I expect to see those households that were historically redlined to have a greater likelihood of having lead pipes today.

2. *How are household demographics correlated with lead pipe presence?*

    I believe that there are significant neighborhood trends of race and income that impact lead pipe usage. Time and time again, we have seen that disadvantaged communities find themselves trapped in a cycle of poverty and inequity, and due to this I believe that we will find a majority of disadvantaged individuals in areas of poorer and older infrastructure, and thus, in locations where lead service lines are more likely to be present (Benfer, 2017; Coates, 2014; Moore, 2012; Sampson and Winter, 2016).

3. *How are remediation efforts being conducted and what factors determine areas of priority?*

    I believe that the neighborhood of priority will contain different characteristics among the different cities analyzed, and thus a specific trend may be inconclusive. I think that many officials face an internal battle between wanting to do good and focusing efforts where they are most needed, and wanting to appease those with influence, which may not be those with the greatest need.

Study Breakdown

To investigate environmental justice through the lens of water lead contamination, lead pipe data from cities across the nation will be analyzed in multiple ways. Mirroring the three research questions of the thesis, the rest of the thesis is divided into three sections: past, present, and future. Within each section, added context will be provided, followed be a description of the methodology, results, and discussion for that research question.

The selected target cities that this thesis will cover include Flint, MI, Toledo, OH, and Trenton, NJ. These are all cities that have experienced lead water contamination crises in recent years, and locations in which efforts have been made to collect data on the presence of lead pipes across the city. These cities were chosen due to data availability since each of these cities makes its lead service line data publicly available. It is important to note that there is some selection bias in the locations chosen based off data availability, and thus cities are not completely representative of the entire U.S., but rather representative of those areas where researchers have taken the time to map out lead pipe usage and where there has been remediation en masse.

STUDY 1 – Past: Historical Redlining Data and Presence of Lead Service Lines

The first part of this thesis attempts to develop a deeper understanding of the impact of past actions and policies on environmental justice across the country today. Specifically, this study investigates the impact that historical redlining from the 1930s has on the presence of lead pipes in households today.

Historical Redlining

Historical redlining is a concept that begins far before the term was coined. In the 1930s, following the Great Depression, FDR developed the New Deal to get the nation back on its feet. Part of this program included the National Housing Act of 1934, through which the Federal Housing Administration (FHA) promoted homeownership across the country by providing loans that were federally backed. However, from its inception, the FHA enforced segregation, drawing lines between neighborhoods for loan restrictions on the basis of skin color (Little, 2020). As a result, redlining has become known as the FHA policy to not insure mortgages for houses that were in or near neighborhoods of color (Rothstein, 2017). The term originates from the actual red lines that were drawn onto maps to identify those neighborhoods that were considered to be less desirable, either due to Black people or foreigners living in them (Little, 2020). In the late 1930s, the Home Owners' Loan Corporation (HOLC) graded neighborhoods into categories based on their racial demographics: "Best" (A) in green, "Still Desirable" (B) in blue, "Definitely Declining" (C) in yellow, and "Hazardous" (D) in red (Domonoske, 2016). Those neighborhoods where Black people lived were labeled as "Hazardous" and were ineligible for FHA backing (Coates, 2014).

This policy has had long-term effects on the US population. Homeownership is a large contributor towards wealth and, largely as a result of redlining, statistics today show that though

Black individuals have about a 60 percent income ratio compared to white individuals, they only have a 5 percent wealth ratio (Gross, 2017). For decades, families of color were unable to buy suburban houses and as a result were unable to accumulate equity. Minority families couldn't send their children to college using their home equity, were forced to depend on their children in old age, and had little wealth to pass down to their children (Gross, 2017). We see the effects today, with 30 percent of white households receiving an inheritance compared to only 10 percent of Black households, and with the average inheritance of a Black household being about half that of a white household (Moss, et al., 2020). Looking at the neighborhoods themselves, we find that the lack of investment in neighborhoods of color due to redlining in the past is still seen in housing values and demographic patterns today (Little, 2020). Recent studies have found that 3 out of 4 neighborhoods that the HOLC graded as high-risk over 80 years ago continue to struggle economically, having low-to-moderate income today (Jan, 2018). The implications of redlining have been widely felt through generations, with people and neighborhoods getting trapped in poverty.

Redlining not only set the stage for the racial wealth gap in the United States, but also contributed to the rampant infrastructure inequity experienced across the country. Two-thirds of the redlined neighborhoods, which have had little investment in them, are inhabited by minority residents, whereas 85 percent of the neighborhoods that were categorized as "Best" are still predominantly white (Jan, 2018). Redlined neighborhoods have repeatedly been the chosen areas for interstate highway development, due to the lack of political opposition in these areas, only adding to the infrastructure inequity (Miller, 2018). Overall, there has historically been under investment and exclusion from resources among those neighborhoods that were historically home to minority communities.

Research has indicated that redlining has resulted in the disproportionate exposure among low-income and minority children to environmental health hazards, including lead (Abdi and Andrew, 2018). Most studies have focused specifically on analyzing elevated blood lead levels and some have looked at lead paint (Fortner, 2021). No study yet has analyzed the presence of lead plumbing in relation to redlining.

Methodology

For this portion of the thesis, analysis was conducted of historical redlining maps, which are publicly available, with lead service line maps. In order to minimize the effects of the most recent efforts to reduce lead contamination, this study focuses on lead data from before remediation efforts began in each city.

Historical redlining mappings categorize neighborhoods with grades A through D, D representing the redlined neighborhoods. Not all of the current neighborhoods have a grade, as these areas may not have been inhabited in the 1930s when the HOLC assigned the grades. Thus, each household finds itself in the location of a neighborhood that either had HOLC grade A, B, C, D, or no grade at all. Using spatial mapping, each household can be assigned a grade (A, B, C, D, NA) based on which neighborhood it is longitude and latitude. With each household assigned an HOLC grade based on historical grading of neighborhoods, a logistic regression can be run to determine whether a household's HOLC grade from the 1930s (or lack thereof) has an impact on the existence of lead pipes in the beginning of the 21st century. Specifically, dummy variable coding will be used to establish HOLC grade D as the baseline, to focus on the impact of being in a redlined neighborhood or not. A basic example of a logistic regression formula is shown here:

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2$$

This model was run multiple times with randomized train and test sets, in order to ensure the accuracy of the results. The sections that follow show results from the model being run on the data set in its entirety. Note that the significance of p values are indicated by the following significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1.

The regression summary will help to indicate the underlying effects of past decisions on cyclical disadvantages that communities face today. In the past, research has worked towards uncovering the geographic dimensions to lead poisoning in children (Griffith, Wheeler, and Johnson, 1998), and this study goes one step further to determine how geographic patterns and government policies impact lead pipe presence.

Results

Flint, MI

Flint has 81,033 addresses with 50 neighborhoods that were given an HOLC grade. Of all the households, about 63.58% have been verified for lead pipes, with lead being found in 37.4% of those verified households.

Table 1.1.1 Flint, MI Statistics

Total Addresses	81033	**Addresses in HOLC graded zones**	62703 (77.48%)
Lead Verified Addresses	51524 (63.58%)	**Addresses in Grade A Zone**	627
Addresses with Lead	19274 (37.41%)	**Addresses in Grade B Zone**	16191
Addresses without Lead	32250 (62.59%)	**Addresses in Grade C Zone**	31690
		Addresses in Grade D Zone	14195

The figures below outline the breakdown of lead pipe presence among households according to their HOLC grade (or lack thereof). Here, a zero represents no lead, while a 1 represents that the household has been confirmed to have lead pipes. The figure to the left shows the breakdown for all of the addresses in Flint, including those that have yet to be physically verified for lead, whereas the figure on the right includes only the data for those households that have been verified for lead pipes.

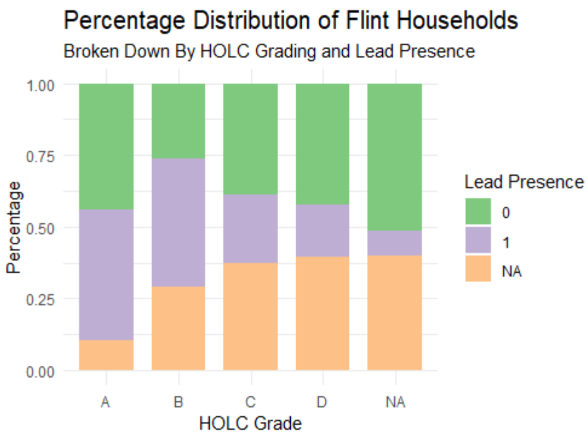


Figure 1.1.1(a): Percentage Distribution of Flint Households with Lead Presence for each HOLC Grade

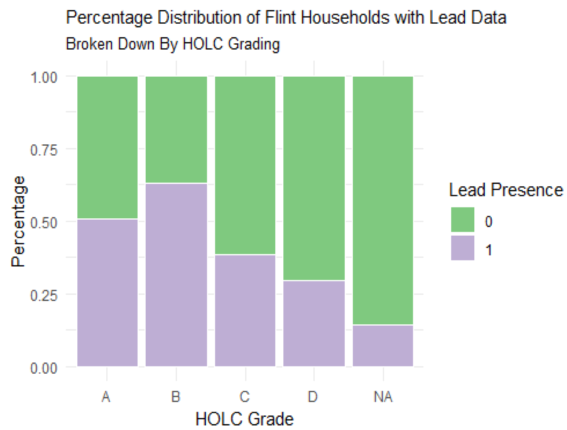


Figure 1.1.1(b): Percentage Distribution of Flint Households with Lead Presence for each HOLC Grade, for those households verified of lead pipes

Figures 1.1.1(b) illustrates that households found in HOLC D neighborhoods (redlined areas) have a smaller percentage of houses with verified lead presence, compared to those houses in non-redlined neighborhoods. This trend is confirmed by the results of a logistics regression studying the impact of HOLC grade on lead pipe presence, which are shown in Table 1.1.2.

Table 1.1.2

HOLC Grades (baseline D)	Hypothesized Directional Relationship	Coefficient	p value	Resultant Relationship
HOLC Grade A	Negative	0.9013	<2e-16 ***	Positive
HOLC Grade B	Negative	1.3960	<2e-16 ***	Positive
HOLC Grade C	Negative	0.4039	<2e-16 ***	Positive
No HOLC Grade	Negative	-0.9356	<2e-16 ***	Negative

has_lead ~ HOLC_AvsD + HOLC_BvsD + HOLC_CvsD + HOLC_NAvsD

Each of the variables in Table 1.1.2 is significant, which indicates that the HOLC grade of the neighborhood does in fact have a correlation to the lead pipe presence today. A household that was graded A is more likely to have lead pipes than a house graded D by a factor of 2.46; a household that was graded B is more likely to have lead pipes than a house graded D by a factor of 4.0; and, a household that was graded C is more likely to have lead pipes than a house graded D by a factor of 1.498. Meanwhile, a household that is not in an area that was graded by the HOLC is 39% as likely to have lead pipes that a house in a grade D neighborhood. The results, in effect, show that not being redlined in fact increases the likelihood of having lead pipes today, which is contrary to the hypothesis.

This trend can be further understood when considering the year that the household was built. Figures 1.1.2(a) and 1.1.2(b) shows the distribution of houses in Flint by the year it was built, taking into account the HOLC grade and lead pipe presence, respectively.

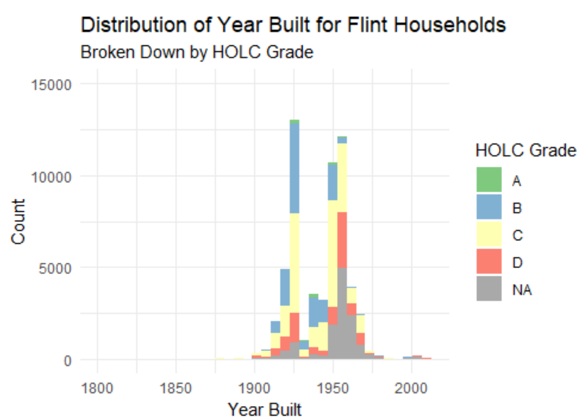


Figure 1.1.2(a): Distribution of the Year Built of Flint Households, broken down by HOLC grade

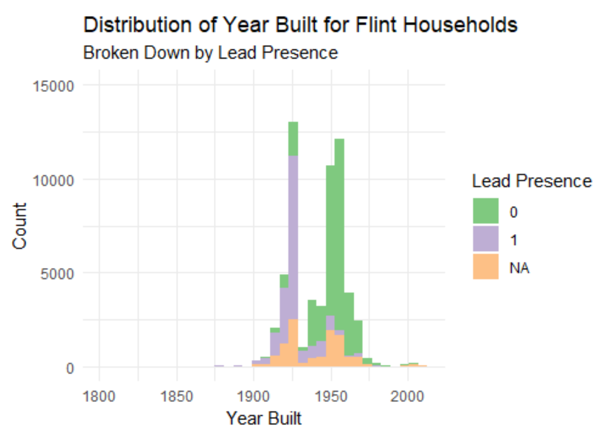


Figure 1.1.2(b): Distribution of Year Built of Flint Households, broken down by lead pipe presence

Figure 1.l.2(a) shows that very few households found in D neighborhoods were built before the late 1960s, at which point a big influx of houses built in redlined neighborhoods is seen. A trend in lead presence can be seen around the same time as well, with the 1950s marking a shift from the majority of households having lead pipes to not having lead pipes. These two trends in tandem likely result in the decreased lead pipe presence in redlined areas that the preliminary analysis showed. Looking into the current events of this time, the Fair Housing Act of 1968 is notable. The Fair Housing Act of 1968 banned redlining practices, and thus the data

was broken down based on whether the house was built before or after 1968. Then, the interaction of HOLC grade and being built while redlining was in practice was analyzed with lead pipe presence. The regression results are shown in Table 1.1.3.

Table 1.1.3

Dependent Variable: Lead Pipe Presence				
Independent Variables	**Hypothesized Directional Relationship**	**Coefficient**	**p value**	**Resultant Relationship**
Built Before 1968	Positive	1.8036	<2e-16 ***	Positive
HOLC Grade A	Negative	2.1905	.000186	
HOLC Grade B	Negative	1.3511	<2.14e-5 ***	Positive
HOLC Grade C	Negative	1.2419	<1.45e-9 ***	Positive
No HOLC Grade	Negative	-0.4565	0.092727	
Pre1968:HOLC Grade A	Negative	-1.1861	.045424 *	Negative
Pre1968:HOLC Grade B	Negative	0.1399	.661582	
Pre1968:HOLC Grade C	Negative	-0.8106	9.43e-5 ***	Negative
Pre1968:No HOLC Grade	Negative	-0.4995	.068803	

*has_lead ~ pre1968 * HOLC_AvsD + pre1968 * HOLC_BvsD + pre1968 * HOLC_CvsD + pre1968 * HOLC_NAvsD*

The above regression results illustrate that when a household is built before 1968, it is more likely to have lead pipes than if it was built after 1968 (which aligns with the fact that research started to indicate the danger of using lead pipes around this time). The regression shows that for a household built after 1968, being in an HOLC B or C neighborhood makes you more likely to have lead pipes. In accordance with our hypothesis, however, results show the interaction effect of being built before 1968 and not being redlined (HOLC grade A or C) decreases the likelihood of lead pipe presence today.

Toledo, OH

Toledo has 100,946 addresses with 78 neighborhoods that were given an HOLC grade. Toledo is still in the early stages of lead pipe verification, and thus only 0.57% of houses have been verified for lead, which strongly diminishes sample size. However, the distribution of those verified houses across HOLC grade mirrors that for those houses not yet verified for lead. This means that though not completely accurate, we can take our group of verified houses to resemble a sample for Toledo. Of all the verified households, lead was found in 33.4% of them.

Table 1.2.1 Toledo, OH Statistics

Total Addresses	100946	**Addresses in HOLC graded zones**	72866 (72.18%)
Lead Verified Addresses	578 (0.57%)	**Addresses in Grade A Zone**	5490
Addresses with Lead	193 (33.39%)	**Addresses in Grade B Zone**	20793
Addresses without Lead	385 (66.61%)	**Addresses in Grade C Zone**	42739
		Addresses in Grade D Zone	3844

The figures below outline the breakdown of lead pipe presence among households according to their HOLC grade (or lack thereof). Here, a zero represents no lead, while a 1 represents that the household has been confirmed to have lead pipes. The figure to the left shows the breakdown for all of the addresses in Toledo, including those that have yet to be physically verified for lead, whereas the figure on the right includes only the data for those households that have been verified for lead pipes.

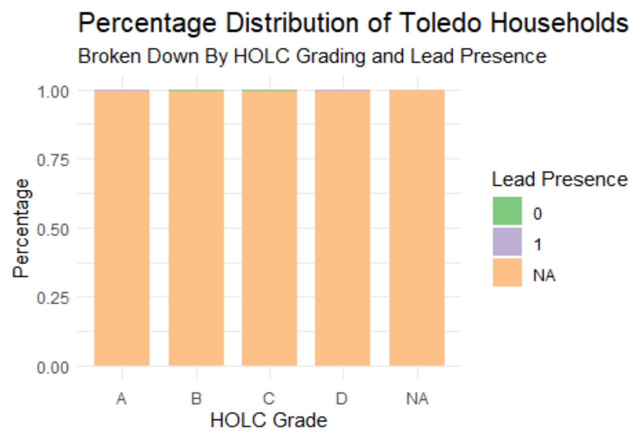


Figure 2.2.1(a): Percentage Distribution of Toledo Households with Lead Presence for each HOLC Grade

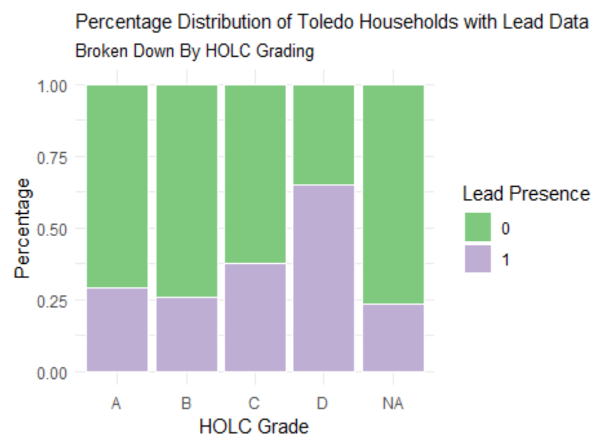


Figure 1.2.1(b): Percentage Distribution of Toledo Households with Lead Presence for each HOLC Grade, for those households verified of lead pipes

Figure 1.2.1(a) shows that for each HOLC grade, the distribution of households is almost entirely “NA” for lead presence due to the low percentage of houses that have been verified in Toledo. This makes Figures 1.2.1(b) much more useful to look at, which illustrates that households found in HOLC D neighborhoods, or redlined areas, have a greater percentage of houses with lead pipes, compared to those houses in non-redlined neighborhoods. This is in line with the hypothesis. This trend is confirmed by the results of a logistics regression studying the impact of HOLC grade on lead pipe presence, which are shown in Table 1.1.2.

Table 1.2.2

HOLC Grades (baseline D)	Hypothesized Directional Relationship	Coefficient	p value	Resultant Relationship
HOLC Grade A	Negative	-1.5063	0.020324 *	Negative
HOLC Grade B	Negative	-1.6764	0.001024 **	Negative
HOLC Grade C	Negative	-1.1282	0.019488 *	Negative
No HOLC Grade	Negative	-1.7940	0.000731 ***	Negative

has_lead ~ HOLC_AvsD + HOLC_BvsD + HOLC_CvsD + HOLC_NAvsD

Each of the variables in Table 1.1.2 is significant, which indicates that the HOLC grade of the neighborhood does in fact have a correlation to the lead pipe presence today. A household that was graded A is only 22% as likely to have lead pipes than a house graded D; a household that was graded B is 18.70% as likely to have lead pipes than a house graded D; and, a household that was graded C is 32.36% as likely to have lead pipes than a house graded D. In a similar fashion, a household that is not in an area that was graded by the HOLC is 16.63% as likely to have lead pipes than a house in a grade D neighborhood.

Once again, the distribution of the year that each house in Toledo was built was analyzed in accordance with HOLC grade. Unlike Flint, there was not a large increase in houses build in HOLC D neighborhoods after around the 1960s, but rather a large increase in households built in neighborhoods that were not redlined, as seen in Figure 1.2.2(a). However due to the limited data of verified lead pipes in Toledo, the distribution of the year the house was built broken down by lead presence (Figure 1.2.2(b)) does not show much of a trend at all.

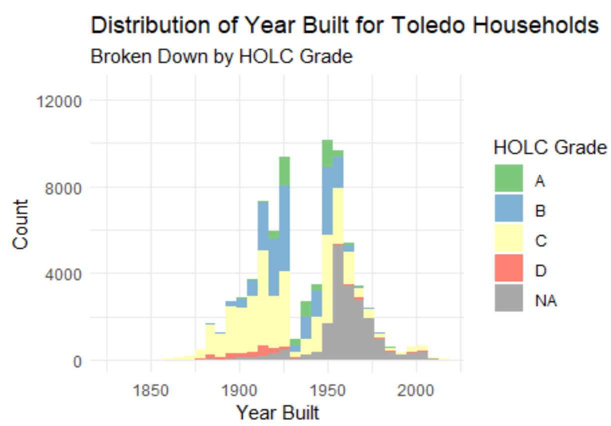


Figure 1.2.2(a): Distribution of the Year Built of Toledo Households, broken down by HOLC grade

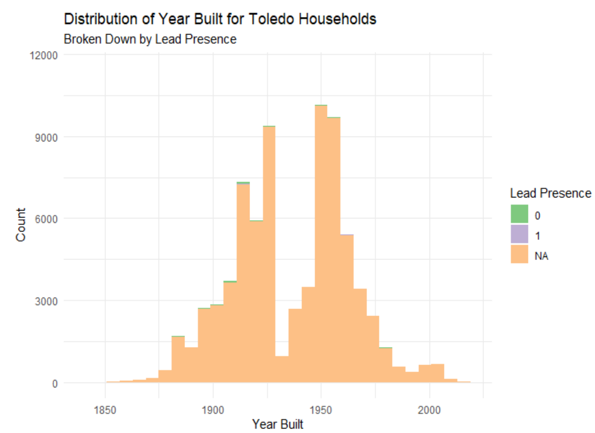


Figure 1.1.2(b): Distribution of Year Built of Toledo Households, broken down by lead pipe presence

Similarly, because of the insufficient number of households that have been verified for lead in Toledo, breaking up the data set between houses built before and after the Fair Housing Act of 1968 produced inconclusive results. In order to conduct a similar analysis, the year that the house was built (without bisecting at 1968) was included as a variable in the logistic regression, with results shown in Table 1.2.3.

Table 1.2.3

Dependent Variable: Lead Pipe Presence				
Independent Variable	**Hypothesized Directional Relationship**	**Coefficient**	**P value**	**Resultant Relationship**
HOLC Grade A	Negative	-1.30848	0.06690 .	Negative
HOLC Grade B	Negative	-1.521004	0.00711 **	Negative
HOLC Grade C	Negative	-1.028198	0.05302	
No HOLC Grade	Negative	-1.174386	0.0485 *	Negative
Year Built	Negative	-0.007737	0.11031	

has_lead ~ HOLC_AvsD + HOLC_BvsD + HOLC_CvsD + HOLC_NAvsD + YearBlt

The regression results in Table 1.2.3 confirms that even when considering the year that a house was built, the HOLC grade still has a significant impact on the presence of lead, with households found in HOLC A, HOLC B, or no HOLC grade neighborhoods being only 27%, 22% and 21% as likely to have lead pipes today than a house found in an HOLC D neighborhood.

Trenton, NJ

Trenton has 62,335 addresses with 36 neighborhoods that were given an HOLC grade. Trenton is somewhere in the middle when it comes to its progress with verifying lead pipe presence. Of all the households, about 10.5% have been verified for lead pipes, with lead being found in 28.1% of those verified households.

Table 1.3.1 - Statistics on Trenton, NJ

Total Addresses	62335	Addresses in HOLC graded zones	62703 (77.48%)
Lead Verified Addresses	6569 (10.53%)	Addresses in Grade A Zone	627
Addresses with Lead	1846 (28.10%)	Addresses in Grade B Zone	16191
Addresses without Lead	4723 (71.90%)	Addresses in Grade C Zone	31690
		Addresses in Grade D Zone	14195

The figures below outline the breakdown of lead pipe presence among households according to their HOLC grade (or lack thereof). Here, a zero represents no lead, while a 1 represents that the household has been confirmed to have lead pipes. The figure to the left shows the breakdown for all of the addresses in Trenton, including those that have yet to be physically verified for lead, whereas the figure on the right includes only the data for those households that have been verified for lead pipes.

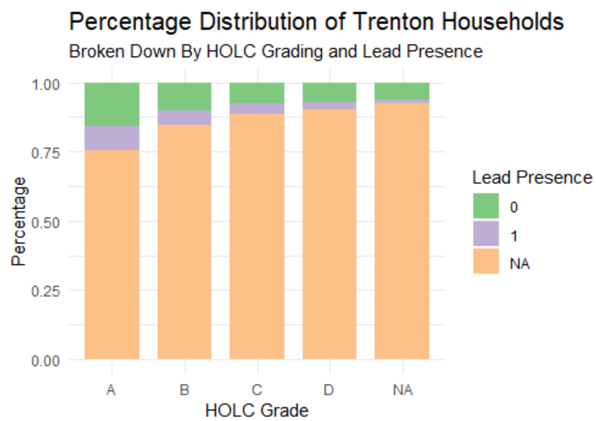


Figure 3.3.1(a): Percentage Distribution of Trenton Households with Lead Presence for each HOLC Grade

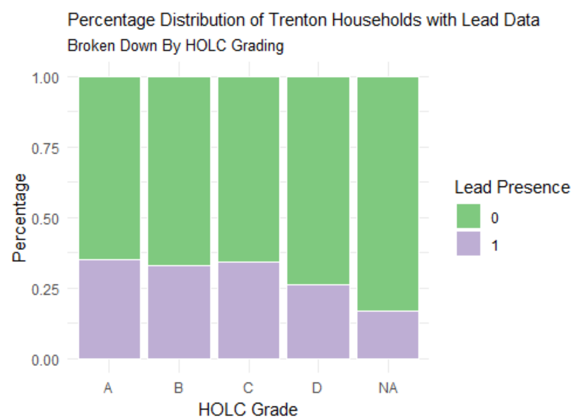


Figure 1.3.1(b): Percentage Distribution of Trenton Households with Lead Presence for each HOLC Grade, for those households verified of lead pipes

Figures 1.3.1(b) illustrates that households found in HOLC D neighborhoods (redlined) have a smaller percentage of houses with lead pipes, compared to those houses in non-redlined, but still HOLC graded, neighborhoods. This trend is confirmed by the results of a logistics regression studying the impact of HOLC grade on lead pipe presence, which are shown in Table 1.3.2.

Table 1.3.2

Dependent Variable: Lead Pipe Presence				
Independent Variable (baseline D)	**Hypothesized Directional Relationship**	**Coefficient**	**Pr(>|z|)**	**Resultant Relationship**
HOLC Grade A	Negative	0.4191	0.00333 **	Positive

HOLC Grade B	Negative	0.3265	0.01016 *	Positive
HOLC Grade C	Negative	0.3891	0.00109 **	Positive
No HOLC Grade	Negative	-0.5699	5.79e-06 ***	Negative

has_lead ~ HOLC_AvsD + HOLC_BvsD + HOLC_CvsD + HOLC_NAvsD

The results for Trenton once again confirm that the HOLC grade of the neighborhood does in fact have a significant impact on lead pipe presence today. A household that was graded A is more likely to have lead pipes than a house graded D by a factor of 1.52; a household that was graded B is more likely to have lead pipes than a house graded D by a factor of 1.39; and, a household that was graded C is more likely to have lead pipes than a house graded D by a factor of 1.48. Meanwhile, a household that is not in an area that was graded by the HOLC is 57% as likely to have lead pipes than a house in a grade D neighborhood. From these results, it looks crystal clear that HOLC D households are less likely to have lead that households found in HOLC A, B or C neighborhoods. However, this story is in fact more complicated when we split up the data by the year that the house was built.

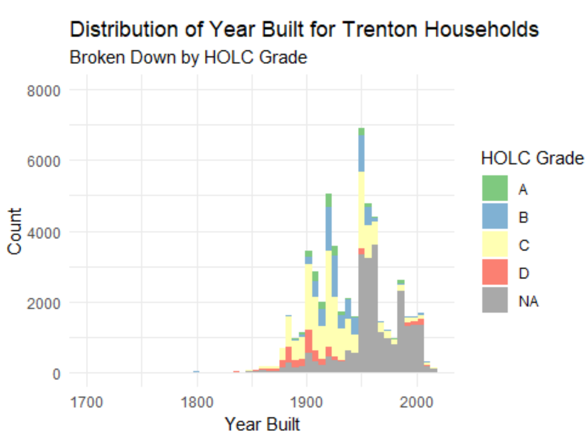


Figure 1.3.2(a): Distribution of the Year Built of Trenton Households, broken down by HOLC grade

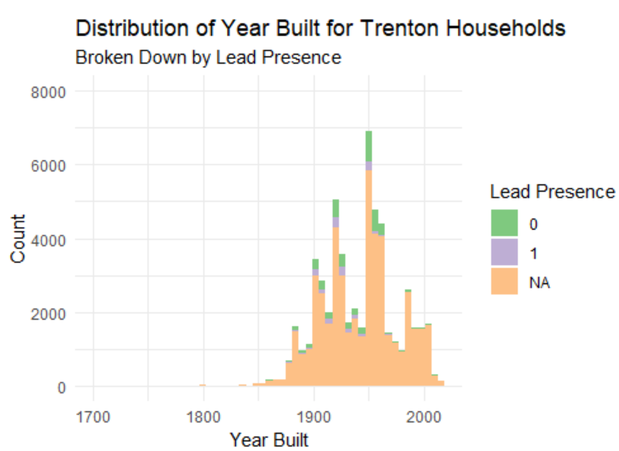


Figure 1.3.2(b): Distribution of Year Built of Trenton Households, broken down by lead pipe presence

Figures 1.3.2(a) illustrates a large increase in houses built in non-HOLC graded neighborhoods around the 1960s, while Figure 1.3.2(b) does not show any specific trend in regard to the year a house was built and lead pipe presence, with a large proportion of households not yet having been verified for lead pipe presence. We once again bisect the data at the 1968 marker in order to account for the effect of The Fair Housing Act of 1968. Table 1.3.3 shows the results of a regression analyzing the interaction of the impact of whether a house was built before or after 1968 and the HOLC Grade of the neighborhood on lead pipe presence.

Table 1.3.3

Dependent Variable: Lead Pipe Presence				
Independent Variables	**Hypothesized Directional Relationship**	**Coefficient**	**p value**	**Resultant Relationship**
Built Before 1968	Positive	-0.1361	0.686878	
HOLC Grade A	Negative	-0.2469	0.681797	
HOLC Grade B	Negative	-0.6592	0.141020	
HOLC Grade C	Negative	-0.2831	0.431555	
No HOLC Grade	Negative	-1.2649	0.000715 ***	Negative
Pre1968:HOLC Grade A	Negative	0.7020	0.257838	
Pre1968:HOLC Grade B	Negative	1.0466	0.025194 *	Positive
Pre1968:HOLC Grade C	Negative	0.7319	0.055137 .	Positive
Pre1968:No HOLC Grade	Negative	0.7826	0.048716 *	Positive

*has_lead ~ pre1968 * HOLC_AvsD + pre1968 * HOLC_BvsD + pre1968 * HOLC_CvsD + pre1968 * HOLC_NAvsD*

The above regression results illustrate that when it is taken account whether or not a household is built before 1968, results change. We see that if a household was built after 1968, which is when redlining practices should have stopped, being in a non-redlined area decreases your likelihood of having lead pipes in your house today. Specifically, for households built after 1968, those found in neighborhoods that were not given HOLC grades are 28% as likely to have lead pipes than a household in an HOLC D neighborhood. The interaction effect of HOLC grade and being built before 1968, however, shifts the impact in the opposite direction. Being built before 1968 and having an HOLC grade of B, C, or none results in an increase in the likelihood of having lead by a factor of 2.85, 2.08, and 2.19, respectively. This interaction effect results in the conclusion that for houses built before 1968, a non-HOLC graded household is 61.7% as likely to have lead than a household in an HOLC D area.

Discussion

The results of Study 1 vary for each of the three cities analyzed. In Flint, we find that for households built before 1968, being in a non-redlined area decreases the likelihood of having lead pipes today. In Toledo, even when we take into account the year a house was built, we find that households built in HOLC D neighborhoods are more likely to have lead pipes today. Finally, in Trenton, results show that for households built after 1968, being in a non-redlined area decreases the likelihood of having lead pipes today. Though the results differ, in each case it is confirmed that the HOLC grade of the neighborhood a house is in has a significant impact on the presence of lead pipes in the household today. These differences in results illustrate the importance in understanding the history of each city analyzed, to comprehend how different policies and acts impacted the community.

In general, it is important to note that of the three cities analyze, Flint has the most data and Toledo the least, and thus accuracy can be seen to follow sample size. The data in Flint tells the most logical and compelling story about the impact of historical redlining on lead pipe presence. As more cities verify pipes in homes and collect data, more cities will be able to tell a story like that for Flint.

STUDY 2 – Present: Demographic Traits and the Presence of Lead Service Lines

The second part of this thesis studies the nature of the relationship between household-level demographic composition and probability of the presence of lead pipes. The goal of this study is to contribute to the discourse about the current status of environmental justice around lead contamination using household level data.

Methodology

For this analysis, the study once again focuses on lead service line data from before any large remediation efforts began in that city. Census data is provided on multiple geographic levels, with the most granular being block group for the American Community Survey (ACS) and block for the Decennial. Paralleling the conscious effort to use lead data from before remediation efforts began, census data is pulled from 2010 or 2013 in order to represent the makeup of the city as accurately as possible in regard to the timeline of the lead crises.

The Decennial 2010 was the default database for all variables, as it is the most accurate source of information. The Decennial refers to the 10-year census which aims to collect information about each household. The ACS, on the other hand, is an annual survey of approximately 3 million households, using this smaller group as a sample for the nation. The ACS conducts 1-year and 5-year studies, and asks more detailed questions than the Decennial Census. As a result, where possible, Decennial data was used from the 2010 census, however, the 5-year ACS 2013 (2009-2013) was used to supplement for those variables of interest not recorded in the Decennial. The Decennial 2010 will be used to pull data on the racial makeup of the households, and the householder age. The ACS 2013 (2009-2013 5-year ACS) will be used to pull data on household ancestry, citizenship status, income, poverty, and educational attainment. Both these data sets use the same geographic breakdown of the nation, and thus can be used in conjunction with little obstacle. However, it is important to note that the variables pulled from the ACS are more likely to be an estimate compared to those pulled from the Decennial.

Each household is found within a specific block group and block. Using geographic Census maps, each household can be tied to the block group and block that it resides in using a GEOID. Census data can then be tied to each household using that block group or block identifier. Note that this means that multiple houses, such as those found within the same block, will share identical census data for a demographic trait. For this reason, when the census data is presented in terms of raw counts for the geographic area, it is transformed into percentages. As such, the census data for each household can be interpreted as the percentage likelihood of that demographic to be found in that household, based off wider data. For example, each household will have a “Black Household Percent”, which indicates the percentage likelihood that that address correlates to a Black household. This percentage comes from the Decennial 2010 variable labeled “Total!!Householder who is Black alone” for the specific block that the household is in, divided by the total households that the census counts for that block. The variables that are pulled from the ACS 2013, have maximum granularity of block group, and thus the percentages created for each household for these variables are a little less specific as the data spans a large area.

Once each household is tied to its demographic statistics, a logistic regression can be conducted in order to determine whether and which demographic traits impact the presence of lead pipes in a household. These traits include household race, Hispanic/Latino makeup, household age, educational attainment, school enrollment, employment, income, receipt of food stamps, citizenship status, ancestry, and language spoken at home. A variety of regression models were trained and tested in order to determine the impact of household demographic traits on lead pipe presence. The results of the most accurate model are shown in the section that follows, while results from other, less accurate, models are included in **Appendix VII**, **Appendix VIII**, and **Appendix IX**, respectively.

This data analysis will add to the discourse on the relationship between lead contamination and disadvantaged communities. It brings a new element to the discussion due to that fact that there has yet to be in-depth analysis conducted on household-level, and little research focuses specifically on lead service line presence in this setting of demographics. This thesis aims to uncover certain trends commons among the neighborhoods with the greatest probability of having lead service lines in order to investigate the current landscape of environmental justice.

Results

Flint, MI

Note that (%) following the variable name indicates that a count was converted into a percentage likelihood for that variable in a household.

Table 2.1.1 - Impact of Demographics on Lead Presence

Dependent Variables: Lead Pipe Presence			
Independent Variables	**Coefficient**	**p value**	**Resultant Relationship**
Vacancy Household (%)	3.9300	<2e-16 ***	Positive
Black Household (%)	-0.8385	<2e-16 ***	Negative
Indigenous Household (%)	2.65100	1.08e-6 ***	Positive
Asian Household (%)	4.605	7.75e-14 ***	Positive
Pacific Household (%)	1.822	0.126	
Other-Race Household (%)	-0.1311	0.777	

Multiple-Race Household (%)	2.011	2.39e-13 ***	Positive
Hispanic/Latino Household (%)	0.3632	0.200	
Female Householder (%)	-1.973	<2e-16 ***	Negative
Median Age of Household	-6.837e-3	2.35e-7 ***	Negative
Median Income of Household	-2.224e-5	<2e-16 ***	Negative
Median House Value	-1.126e-5	<2e-16 ***	Negative
Householder Not a US Born Citizen (%)	-12.1200	<2e-16 ***	Negative
Household Language Not English (%)	-2.823	5.41e-5 ***	Negative
Householder Not in Labor Force (%)	0.8786	<2e-16 ***	Positive
Recipient of Food Stamps (%)	-2.515	<2e-16 ***	Negative
Householder Completed High School (%)	-14.5900	<2e-16 ***	Negative
Householder Completed Some College (%)	-8.811	<2e-16 ***	Negative
Householder Completed a Bachelor's Degree (%)	-11.63	<2e-16 ***	Negative
Ratio of Income to Poverty Level: 1-2 (%)	-1.787	<2e-16 ***	Negative
Ratio of Income to Poverty Level: 2+ (%)	4.930	<2e-16 ***	Positive

AIC: 55005

The results in Table 2.1.1 show that in Flint, vacancy, being an Indigenous, Asian, or multiple-race household (as compared to a white household), not being in the labor force, and having a ratio of income to poverty level above 2 (as compared to below 1) increases the likelihood of lead pipes in Flint households. At the same time, being a Black household (as compared to a white household), having a female householder (as compared to a male householder), not being a US Born Citizen, not speaking English in the household, being a recipient of food stamps, the householder having completed high school, some college, or a bachelor’s degree (as compared to having not completed high school), and the ratio of income to poverty level being 1-2 (as compared to below 1), decrease the likelihood of a household to have lead pipes. Additionally, an increase in the age of a household, median income of the household, or house value will decrease the likelihood of that household having lead pipes.

Toledo, OH

Note that (%) following the variable name indicates that a count was converted into a percentage likelihood for that variable in a household.

Table 2.2.1 - Impact of Demographics on Lead Presence

Dependent Variables: Lead Pipe Presence			
Independent Variables	**Coefficient**	**p value**	**Resultant Relationship**
Vacancy Household (%)	-1.045	0.3590	
Black Household (%)	-0.2154	0.6499	
Indigenous Household (%)	3.711	0.5411	
Asian Household (%)	-1.893	0.7541	
Pacific Household (%)	-6.526e+2	0.9853	
Other-Race Household (%)	1.603	0.5901	
Multiple-Race Household (%)	-2.166	0.5565	
Hispanic/Latino Household (%)	-4.339	0.0454 *	Negative
Female Householder (%)	-2.674	0.0682 .	Negative
Median Age of Household	-1.497e-2	0.2754	
Median Income of Household	-1.316e-5	0.2481	
Median House Value	-7.286e-6	0.2324	
Householder Not a US Born Citizen (%)	-6.678	0.2823	
Household Language Not English (%)	9.483	0.0866 .	Positive
Householder Not in Labor Force (%)	4.619	0.2135	
Recipient of Food Stamps (%)	1.614	0.4156	
Householder Completed High School (%)	-0.4005	0.8955	

Householder Completed Some College (%)	0.4048	0.8736	
Householder Completed a Bachelor's Degree (%)	-0.7123	0.7754	
Ratio of Income to Poverty Level: 1-2 (%)	-0.5949	0.4600	
Ratio of Income to Poverty Level: 2+ (%)	-0.7150	0.5360	

AIC: 639.06

The results in Table 2.2.1 show that a household not speaking English increases its likelihood of having lead pipes, while a household being Hispanic/Latino (as compared to not being Hispanic/Latino) or having a female householder (as compared to a male householder) decreases the likelihood of that household having lead pipes in Toledo.

Trenton, NJ

Note that (%) following the variable name indicates that a count was converted into a percentage likelihood for that variable in a household.

Table 2.3.1 - Impact of Demographics on Lead Presence in Trenton

Dependent Variables: Lead Pipe Presence			
Independent Variables	**Coefficient**	**p value**	**Resultant Relationship**
Vacancy Household (%)	2.200e-2	0.956634	
Black Household (%)	0.3026	0.061982 .	Positive
Indigenous Household (%)	-3.673	0.128925	
Asian Household (%)	-2.550	0.018518 *	Negative
Pacific Household (%)	1.045	0.617936	
Other-Race Household (%)	-0.7601	0.187556	
Multiple-Race Household (%)	-0.6118	0.503066	
Hispanic/Latino Household (%)	0.838	0.029464 *	Positive
Female Householder (%)	9.218e-2	0.844883	

Median Age of Household	-1.550e-2	0.001937 **	Negative
Median Income of Household	4.385e-6	0.020365 *	Positive
Median House Value	-3.236e-6	0.000863 ***	Negative
Householder Not a US Born Citizen (%)	2.182	0.007801 **	Positive
Household Language Not English (%)	-1.815	0.002468 **	Negative
Householder Not in Labor Force (%)	-0.3550	0.011415 *	Negative
Recipient of Food Stamps (%)	-3.290	0.000172 ***	Negative
Householder Completed High School (%)	1.435	0.083138 .	Positive
Householder Completed Some College (%)	1.608	0.078868 .	Positive
Householder Completed a Bachelor's Degree (%)	-1.053	0.106295	
Ratio of Income to Poverty Level: 1-2 (%)	-0.8018	0.043174 *	Negative
Ratio of Income to Poverty Level: 2+ (%)	0.3969	0.276711	

AIC: 7533.7

The results in Table 2.3.1 show that being a Black household (as compared to a white household), being a Hispanic/Latino household, not being a US born citizen, and the householder having only completed high school or some college (as compared to not having completed high school) increases the likelihood of having lead pipes in Trenton households. As the median income of a household increases in Trenton, so does the likelihood that it has lead pipes. At the same time, being an Asian household (as compared to a white household), not speaking English in the household, the householder not being in the labor force, being a recipient of food stamps, and having a ratio of income to poverty level between 1 and 2 (as compared to below 1) decreases the chances of a household having lead pipes today. Additionally, an increase in the age of the household and house value decreases the likelihood of lead pipes in the home.

Discussion

The impact of demographic traits on household lead pipe presence differs from city to city, as it did with HOLC grade. For example, when looking at race specifically, we find that in Flint, a household that is Indigenous, Asian, Pacific, Other, or some mix of multiple races is more likely to have lead pipes than a white household, though a Black household is less likely to have lead pipes than a white household. In Toledo, a regression on the impact of household race on lead presence shows that Black, Indigenous, and other (non-white) households are more likely to have lead pipes than a white household. In Trenton, a regression on the impact of household race on lead presence shows that Black, Pacific, mixed, and other (non-White) households are more likely to have lead pipes than a white household.

Note that the number of demographic traits that have a significant impact on lead presence decrease as the sample size of the city decreases. As such, we find the majority of variables in Flint to be significant, while only three variable have significance in Toledo.

The figure below shows the odds ratio for each demographic variable on lead pipe presence for each city. These results are all included on a single forest plot in order to better comprehend the difference from city to city. The odds ratio represents the probability of a household having lead pipes divided by the probability of not having lead pipes. A positive odds ratio indicates that the variable increases the likelihood of having lead pipes. Note that the result for Pacific Household (%) in Toledo was much greater in magnitude than any of the other odds ratios, and as such had to be cut out of the frame.

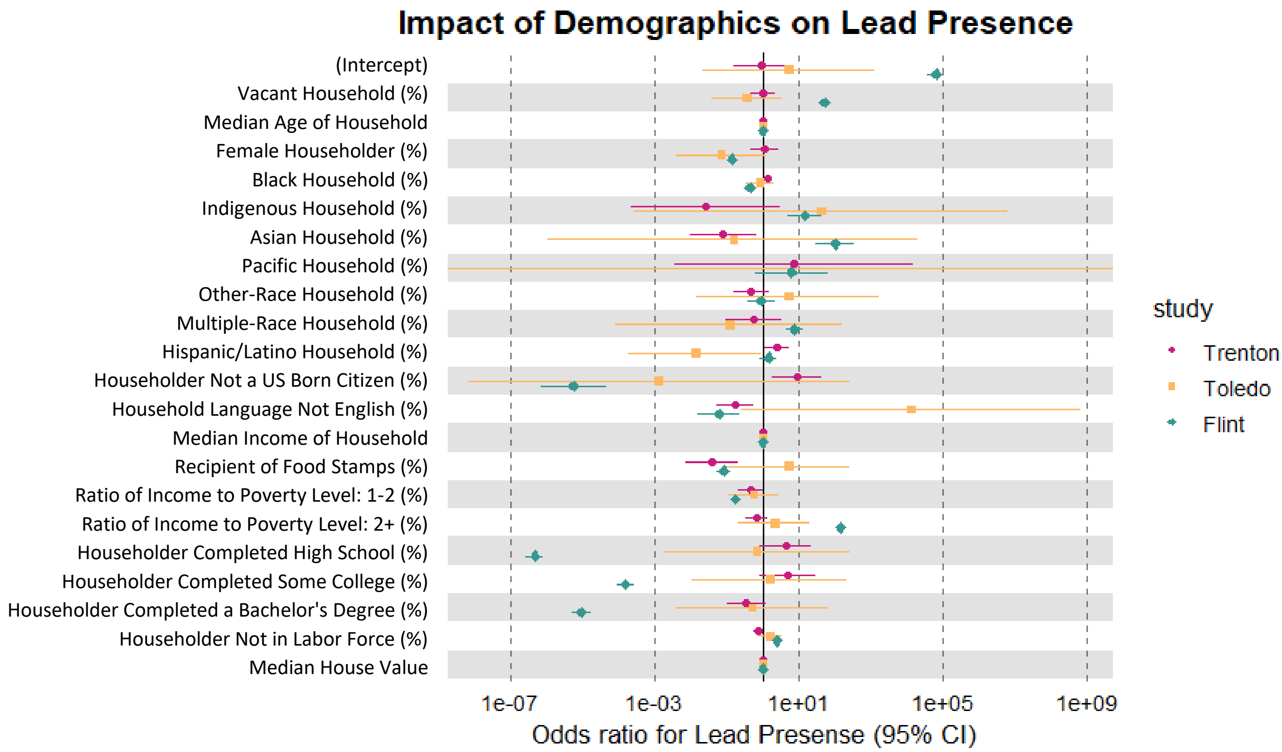


Figure 2.4 : Forest Plot with Odds Ratios for Demographic Traits in Flint, Toledo, and Trenton

This visual representation showcases just how much variety is seen in the results from city to city. Similar to with the Study 1, this affirms that it is important to take an individual lens with each city analyzed. Each city that this thesis conducts analysis on has a unique current demographic make-up, and thus the impact of different traits on environmental equity will vary by city. At the same time, the result of this study to confirm that in general various demographic traits have an impact on lead pipe presence.

STUDY 3 – Future: Remediation Efforts

The final part of this thesis aims to develop a better picture of the future of environmental justice in the U.S. In this third study, a meta-analysis is conducted in order to allow for a side-by-side comparison of remediation efforts between cities. This is supplemented by spatial mappings of the cities, with specific focus on the first neighborhood to receive aid in each city.

Landscape of Remediation Activity

The FWC opened the eyes of many when it came to the way that governments respond to lead water contamination crises. The replacement pilot in Flint replaced pipes in 36 homes around the city based on risk factors such as elevated water lead levels, pregnant women, and children younger than 6. Hazardous materials were found in 33 of the 36 (McDaniel, 2017). This marked the first houses in Flint to be physically verified of lead service lines. In the following months, the state and federal government together directed more than $125 million to replace the lead service lines in Flint, however, they still lacked accurate data on the location of the lead service lines in question. Subsequently, a research team developed a predictive model to inform where there was the greatest probability of lead pipes, aiding the government in focusing their efforts (Abernethy et al., 2018). Following suit, many cities across the US began to map out their lead service line usage in order to aid remediation efforts.

Cities across the US have devoted large sums of money towards lead service line replacement. Biden's infrastructure plan includes $15 billion to replace lead pipes across the nation, with this funding going to EPA administered programs (Filippelli, 2021). As officials begin the make decisions as the how this funding will be used, and which lead pipes will be replaced first, questions emerge about the logic being used. Welfare programs have time and time again perpetuated racial discrimination. The concept of redlining, after all, was developed out of the New Deal, a welfare program. Other aspects of the New Deal similarly gave priority to white people and excluded Black people from key benefits, often disguised using terms such as "work requirements" and "drug testing" (Ward, 2020; Allen, 2020). Today, we see that programs such as the Temporary Assistance for Needy Families continue to reflect the racist legacy of cash assistance (Floyd, et al., 2021). This is cause for concern when it comes to ensuring equality with lead service line replacement.

Already, some inequalities are being uncovered in the approaches being used. Namely, Michigan is currently undergoing a 20-year effort to replace every lead service line in the state, which is to be paid mainly by ratepayers. Escanaba, a city in the Upper Peninsula, has requested an additional 10 years in order to minimize the price increase on ratepayers, worrying that a large portion of its resident won't be able to handle any further increase in water rates (House, 2021). This approach to lead service line replacement clearly hurts lower income communities.

A further problem presents itself when taking into account that most infrastructure projects to replace lead pipes rely on customers to pay for the replacement of lead pipes found on their private property. Thus, in order to have lead pipes fully replaced, homeowners must invest their own money, leading to discrepancies between households of different income level and race. A study in DC found that two-thirds of households in the wealthiest areas fully replaced their lead pipes during ongoing infrastructure projects, as compared to only one quarter in areas with the lowest median incomes, and that full replacements initiated by residents outside of infrastructure work most often took place in wealthier, predominantly white neighborhoods (Lovell, 2020).

There is currently no literature that includes all of the information about remediation activity in these cities in one central location. This thesis looks to explore the way in which cities are conducting their lead service line replacement efforts and determine best practices. Additionally, no studies have focused on the priority areas of remediation efforts, and thus this thesis also works to determine what factors lead to prioritization of certain neighborhoods.

Methodology

This study will work to develop a better picture of the future of environmental justice in the U.S by conducting a meta-analysis of the remediation efforts in each city of focus. Condensing all the information of each cities' remediation efforts in one place will allow for a side-by-side comparison of the different approaches.

Additionally, special interest will be given to the neighborhood that received the first aid in each city. As each of the cities analyzed began to recognize their lead contamination problems, media flocked the surrounding areas to be the first the write about the story. The media's hunger for a story will provide the necessary information on community responses. Specifically, this study will determine which neighborhood within each city was the "first dig", or the first neighborhood to receive aid and attention from the government to repair the lead contamination. This research is less about how much media coverage a water crisis had, and more about using media to determine the location of the "first dig". This location is of special important because it shows the intentions of remediation efforts and how often times they exacerbate inequity. It is important for programs such as remediation efforts to be trustworthy in the eyes of the community. For these first neighborhoods of focus, spatial mappings will be developed to showcase the traits of the prioritized area in order to analyze which factors were used by city governments to determine where to begin their efforts. Specifically, the lead pipe presence and HOLC grade of the areas relative to the entire city will be analyzed.

Results

Flint, MI

In 2016, Flint began a replacement pilot, selecting 36 homes around the city to replace pipes in based on risk factors such as elevated water lead levels, pregnant women, and children younger than 6. Of the 36 houses, 33 were found to hazardous materials (Abernethy et al., 2018). These 36 houses marked the first houses in Flint to be physically verified of lead service lines. As of 2021, 26,819 service lines had been inspected and 9,941 were found to be lead or galvanized pipes and have been replaced (Carmody, 2021). As of April 2021, an estimated 500 homes remain awaiting excavation, and the July to December 2021 testing period signaled improved water quality with 7ppb (Flint City Hall, 2022).

As service line replacement became a top priority for Flint, the Michigan state legislature appropriated $27M towards the replacement process, with the U.S. Congress later allocating another $100M towards the effort (Abernethy et al., 2018). The lead pipe replacements were to be execute through the Flint Fast Action and Sustainability program (FAST Start). As stated in FAST Start Program Update and Summary for 2017, Flint uses a variety of selection criteria for deciding where to replace pipes, including the amount of lead in the water, determined by testing, the age of water in the area’s distribution system, if there are children under 6 years old in the home, if there are elderly adults in the home, and the concentration of lead/galvanized lines in the area. Additionally, to be considered for the replacement, homes must both be occupied and have an active water account. Following the replacement pilot, the FAST Start Program began with Project Scope, which aimed to serve those neighborhoods with the highest concentration of lead pipes first (McDaniel, 2017).

Flint began its replacement efforts by using data science to produce a predictive model for lead presence across households in Flint, MI to aid in decision making about location selection. Given the outdated records, the city did not have any clear indication of which houses had lead pipes, and thus worked with a team of researchers who used a variety of factors to assign each household with an estimated probability that it contained hazardous materials. This model turned out to be incredibly accurate, with 6,228 of the 8,833 pipes dug in 2017 were found to be lead or galvanized and replaced, resulting in a 70 percent accuracy rate (Ahmad, 2019). In 2018, however, the city turned instead to a Los Angeles-based engineering firm to lead their replacement program. During that time, 10,531 pipes were dug, with only 1,567 having hazardous pipes, resulting in only a 15 percent accuracy rate (Ahmad, 2019). Following the ruling from the district court, in 2019 Flint was required to use the data-driven model for the replacement program.

The team who led the data-driven approach to the replacement program used their learnings from Flint to propose a generic framework for municipalities across the world working to efficiently replace hazardous water infrastructure at a large scale. Their work shows that using a holistic, data-driven approach has the potential to reduce the fraction of unnecessary replacements to 2%, which leads to a 10% reduction in the effective cost of each replacement and savings of about $10M (Abernethy et al., 2018)

With the FWC being the whistleblower event for other water crises across the US, it is also becoming the model for lead replacement efforts. The Biden administration has been advocating for other cities to replicate Flint's pipe replacement experience, though some constituents worry that that more-affluent suburbs may rush in and deplete the proposed federal funding, leaving out disadvantaged communities (Carmody, 2021). This brings attention to the need for money to be allocated first for communities of color. In Flint, all the remediation work was done at no cost to residents (City of Flint, 2022). This won't always be the case, as we will see in the following cities, and as a result low-income households are likely to be left behind. At the same time, Flint's program had to face obstacles of its own in achieving success, such as the fact that one third of the city's homes are not occupied, a rate that is the highest in the country (Schwartz, 2018).

From the FAST Start Program, a schedule of which neighborhoods would be focused on was announced in 2017 (**Appendix X**). The project claimed that neighborhoods first served would be those that head the highest concentration of lead pipes. The two figures below show the outline of the neighborhood of first priority on mappings of lead service lines and of HOLC grade.

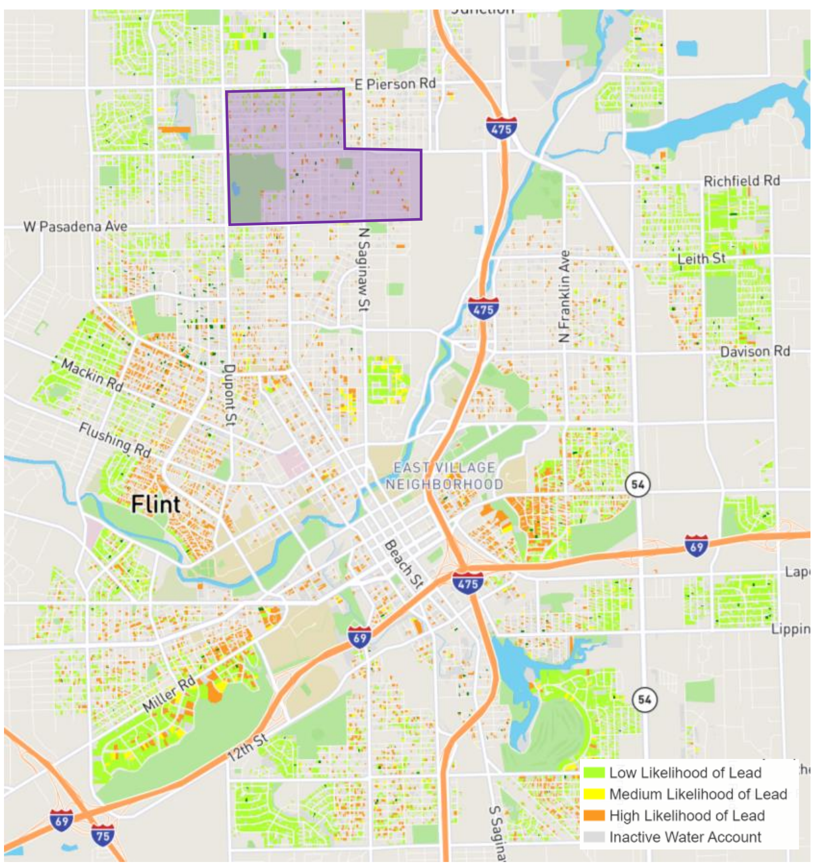


Figure 3.1.1: Lead Service Line Map for Flint, with outline of the first neighborhood focused on for pipe replacement

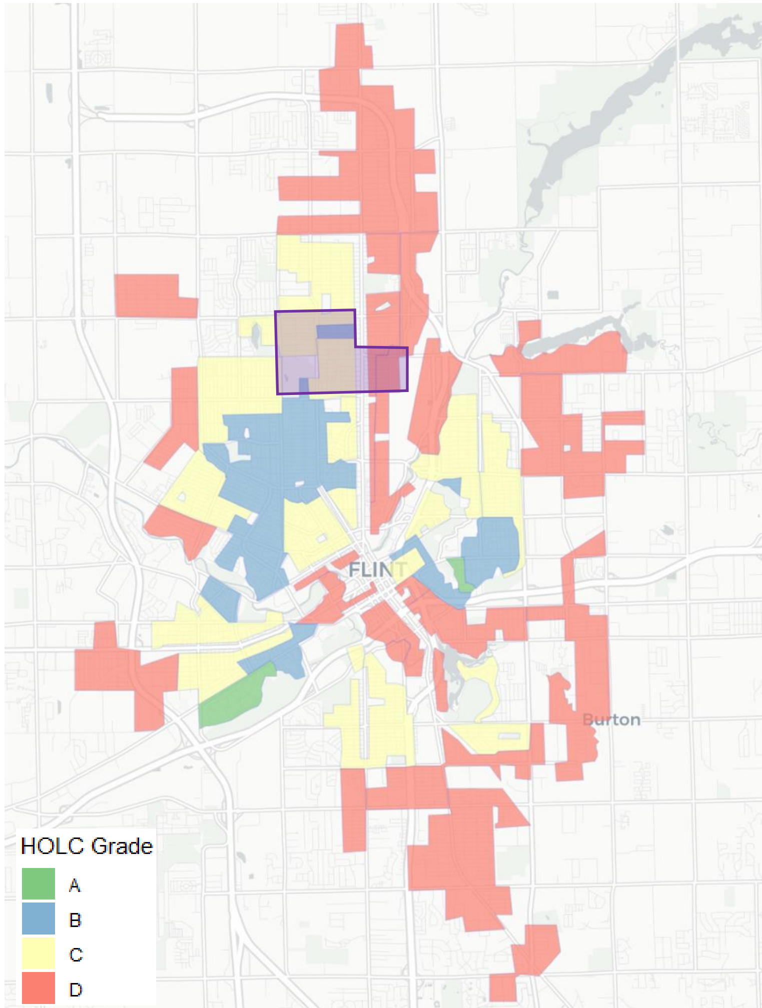


Figure 3.1.2: HOLC Grade Map for Flint, with outline of the first neighborhood focused on for pipe replacement

Figures 3.1.1 shows that the first neighborhood of focus may not be the area with the most concentrated number of households that had a high likelihood of lead, however, it is definitely not an area with a majority of houses that have a low likelihood of lead. Rather, it seems that the area has a significant number of vacancies, but that of the houses that are inhabited, most of them have a high likelihood of lead pipes.

Figure 3.1.2 shows that the first neighborhood of focus has houses that are mostly graded B or C, and a few households graded D. Given that so much of Flint is graded D, it is interesting that the area of focus chosen is very minimally a HOLC D zone, however, at the same time, it is a good sign that the area of focus is not one of the two HOLC A graded neighborhoods of Flint.

It is important to note that the schedule of neighborhoods focused on created by the FAST Start Program predates most of the data-science driven efforts of BlueConduit, and as a result the actual remediation efforts proceeded differently than planned. Instead the efforts of BlueConduit allowed for focus to be given in the households that were most likely to have lead in them. **Appendix XI** shows the current progress of Flint in replacing all of it lead pipes.

Toledo, OH

The city of Toledo developed a replacement program to remove all lead drinking water service lines in tandem with an initiative to educate residents who have lead pipes. The program distinguishes between city-side and customer-side replacement, though both sides are fully financed by the city through grants, such as the American Recovery Plan Act. In August 2018, all homeowners with suspected lead service lines or galvanized steel service lines with lead goosenecks were sent out letters regarding replacement (Toledo City Council, 2022). If the homeowner responded “yes”, they were included in the pool of participants for replacement at a discounted cost, however, if they failed to respond or responded “no”, then they must register online to be enlisted for the customer-side replacement program. The goal of the program is to replace the approximately 3,000 lead lines in Toledo by the end of 2024 (Hubert, 2022).

The first phase of the program focuses on the neighborhood of Junction, to be followed by Old West End, East Toledo, Monroe-Auburn, Vistula, and Broadway Corridor in the subsequent phases (Toledo City Council, 2022). Note that, since Toledo distinguishes between the city-side and customer-side for their replacement program, this timeline is specifically for the city-side, whereas the customer-side will follow based on the pool of participants that registers for replacement.

The figures below show the outline of the Junction neighborhood on mappings of lead service lines and of HOLC grade.

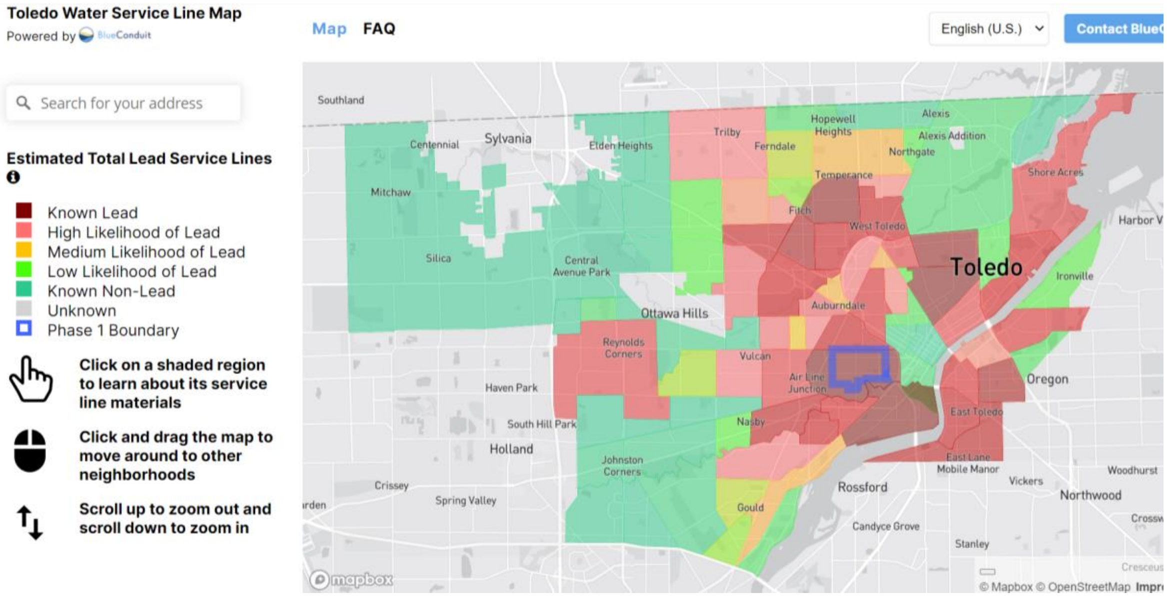


Figure 3.2.1(a): Lead Service Line Map for Toledo, with outline of the first neighborhood focused on for pipe replacement

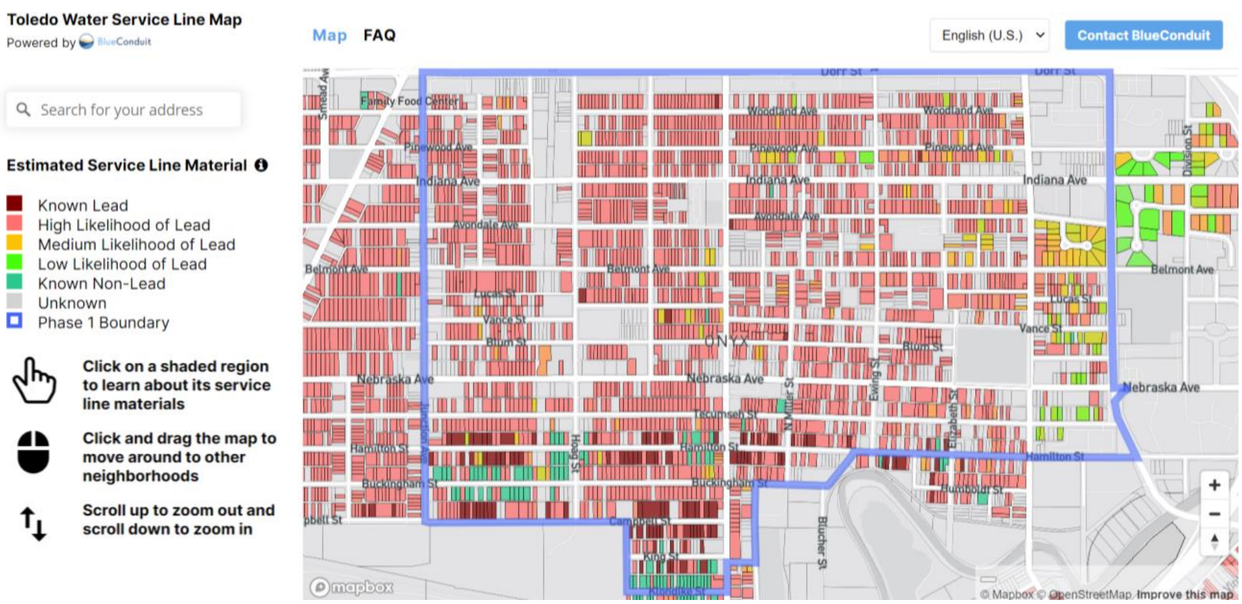


Figure 3.2.1(b): Lead Service Line Map for Toledo, zoomed in on the first neighborhood of focus for pipe replacement

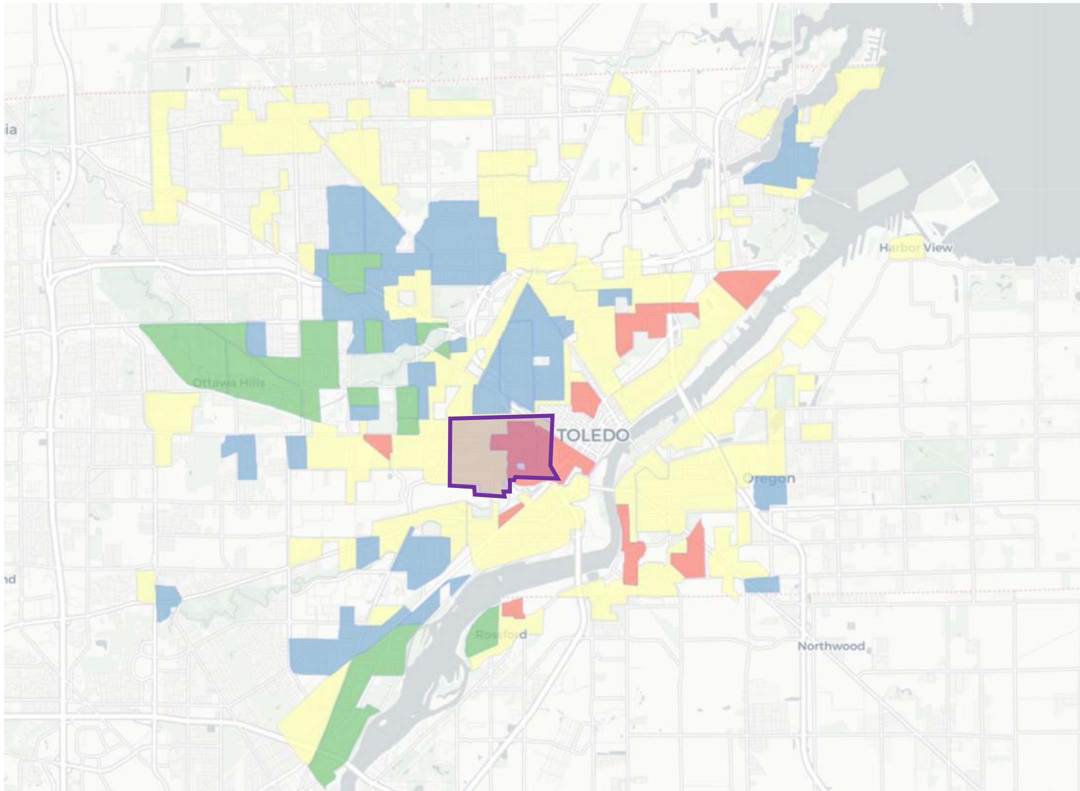


Figure 3.2.2: Toledo Historical Redlining, with Phase 1 Neighborhood, Junction, outlined

Figure 3.2.1(a) and (b) show that the Junction neighborhood is one with a high likelihood of lead as well as a large amount of confirmed lead. This makes it a great area of focus for remediation efforts since these residents are at high-risk for lead exposure. Figure 3.2.2 shows that Junction is made up of HOLC C and D households. This neighborhood is one of the areas in Toledo with the worst HOLC grading, and thus it is a good indication that Toledo is choosing to focus on this community first.

Toledo has made a clear emphasis on their intention to ensure that remediation efforts are distributed equitably among all its residents. As Kurt Thiede, the EPA regional administration that oversees Toledo, put it, the aim is to "to ensure clean air and clean water are basics shared by all, regardless of your ZIP code." (Goldstein, 2020). Similar to Flint, the Toledo efforts plan to use machine learning to combine historical data and technology to identify targets for the lead service line replacements and to reduce lead exposure risk for the city's most vulnerable communities. In order to accomplish this, Toledo plans to pair its replacement program with a public education campaign with the goal of helping the most vulnerable residents minimize their lead exposure as the city continues its remediation efforts. As the EPA notes, the ongoing presence of lead pipes in households "poses a serious health risk to the community, especially for low-income and minority populations" (Goldstein, 2020).

Looking into Junction, the area of focus for Phase 1 of Toledo's remediation efforts, we are able to learn a bit more about the demographic makeup of the neighborhood.

Table 3.2.1 – Toledo Area vs Junction Demographics

Toledo		Junction	
Average Year Built	1937.206	Average Year Built	1914.438
Median Household Income	$32,116.3	Median Household Income	$30,127.25
Est. Black or African American Population (%)	43.31819%	Est. Black or African American Population (%)	83.4375%
Vacancy (%)	16.76737%	Vacancy (%)	29.4375%

The above table shows the differences between the makeup of Junction compared to Toledo at large. We find that the average house in Junction is older than that of Toledo and that the median household income is lower. At the same time, Junction has a larger Black population and more vacancies than Toledo in general. This is an indication that the remediation efforts in Toledo are in fact attempting to focus on low-income and minority populations as stated.

Contractors are currently in the process of completing Phase 2 of the program, which will be complete in Spring 2022 (Toledo City Council, 2022). Additional program phases will start in 2023.

Trenton, NJ

Trenton Water Works is leading a $150-million Lead Service Line Replacement Program across the city, with the goal to remove all lead service lines from the system within a 5-year time span. The program was kicked off at the home of Jeffrey and Jane Rosenbaum in West Trenton's Berkeley Square neighborhood. The program also intends to make significant upgrades to the water-filtration plant as well as water-distribution system and facilities (Department of Water & Sewer, 2022). This aligns with the statewide goal to replace all lead service lines in New jersey by 2031. (Trenton Water Works, 2022). As shown in Figure 3.3.1, Trenton has a significant amount of lead compared to other areas of New Jersey, and thus is an important area of focus.

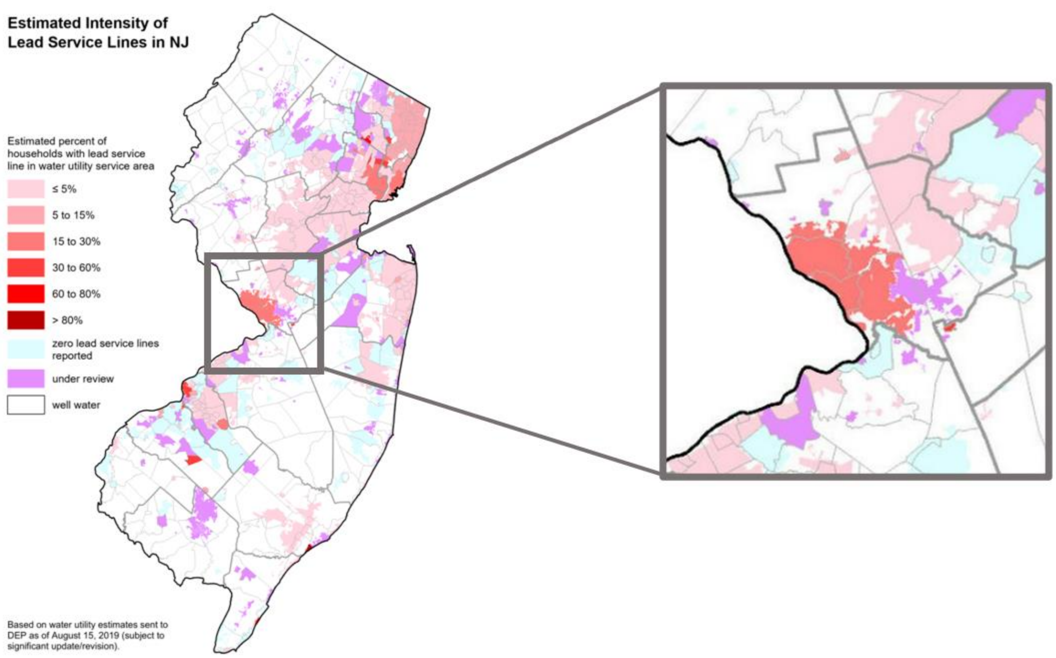


Figure 3.3.1: Lead Service Line Map for New Jersey, with focus on Trenton

Trenton Water Works serves more than just Trenton, and thus the replacement program includes townships other than Trenton. These other townships are often identified to be part of

Trenton by, for example, the United States Postal Office. The replacement schedule began the remediation efforts in the Lawrence and Hamilton Townships in January 2020, with Trenton and Ewing Township following closely behind in February. Replacements also followed based on the time at which residents signed up for the program, with those signing up in 2019 getting their replacements done in 2020 (International Association of Plumbing & Mechanical Officials, 2020). As of the beginning of 2022, with Phase 1 and 2 underway, 25% of the lead service lines in Trenton has been replaced, which the phases finishing in March (Trenton Water Works, 2022).

Unlike the other two cities analyzed, Trenton does not ensure full coverage of the pipe replacement. However, they do ensure that the cost will be no more than $1,000 for the resident (Trenton Water Works, 2022). This is worrisome, since this cost can be a barrier for disadvantaged communities to have their lead pipes replaced, and thus can result in equity in remediation across the city. According to the Water Work' Chief Engineer, the hope with this project is that in the future, the replacements will be mandatory and at no cost to residents, with fund coming from the state infrastructure bank as well as a federal program (Salvatelli, 2022)

Little information is given as to the reasoning that the city used to decide on the order of the replacement schedule. Below Figure 3.3.2 and Figure 3.3.3 show where the areas of priority focus are on maps showing lead pipe presence and HOLC grading.

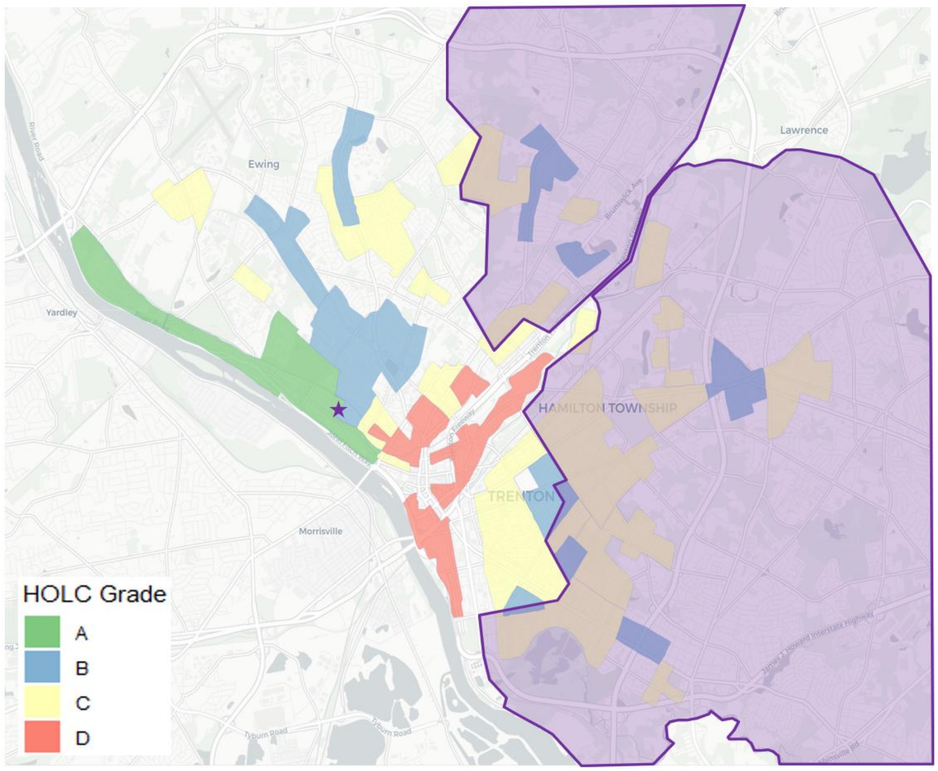


Figure 3.3.3: HOLC Grade Map for Flint, with outline of the first neighborhood focused on for pipe replacement

Discussion

Each city follows a similar remediation plan, with the intention to focus on the areas of greatest need first. In most cases, this means attempting to identify the areas with greatest lead pipe presence, however other cities choose to focus on other factors as well. For example, the Pittsburgh Water and Sewer Authority (PWSA) focuses its neighborhood-based lead line replacement program by using community-based data to prioritize the most vulnerable neighborhoods with prioritization given to locations such as daycare centers (Pittsburgh Water and Sewer Authority, 2022). With Pittsburgh we also see the requirement for the PWSA to prioritize replacement for residents in high-risk neighborhoods, while also limiting the practice of replacing only part of a lead service line, by a settlement recently approved by the Pennsylvania Public Utility Commission, (NRDC, 2022).

It is important for each replacement program to consider the unique makeup of the city when approaching remediation. In each city, different factors play a role on lead exposure, and thus an individual approach must be used. At the same time, using data driven-approaches within this context has proven time and time again to be incredibly accurate in reducing lead exposure through pipe replacement.

As NRDC attorney Pete DeMarco says, “The burdens of lead-contaminated water fall most heavily on low-income families and communities of color, which is why it is so important to prioritize lead service line replacements in those neighborhoods where residents are at greatest risk.”

Conclusion

The results of this thesis show different findings from city to city. However, for each of the cities analyzed, it is clear that HOLC grade and demographics play a role on lead pipe presence today in households. These results only emphasize the merits of conducting similar studies on a national scale in order to approach prevention and remediation of lead water crises with greater knowledge.

Study 1 allowed for a greater understanding of the impact of past actions on the current landscape of lead pipe presence. Specifically, the results show that while the impact of historical redlining on lead pipe presence differs from city to city, in general we can see that HOLC grade, or lack thereof, has a significant impact on lead pipe presence today.

Study 2 focused on using demographic data to better describe the current status of environmental justice in the U.S. as it relates to lead pipe presence. In this study, results similarly showed that the impact of demographics on lead pipe presence differed by city, but in general we saw that most demographic traits were significant.

Lastly, Study 3 provided a more forward-looking perspective to the status of environmental justice in the nation. The meta-analysis illustrated the concerted efforts of each city to develop a lead pipe replacement program, with the goal of targeting those most exposed to lead first. By analyzing both lead pipe presence and HOLC grade with respect to the areas of focus, this study saw that city governments are making conscious efforts to ensure the remediation effort is as equitable as possible.

Altogether, the results provide greater knowledge of at-risk populations for lead exposure from an infrastructure perspective. This can help to develop more appropriate responses to current and future water crises.

Limitations

The biggest limitation of this study is due to a lack of data on the subject of interest. This presents itself in two ways, first being the minimal geodiversity of the cities that are analyzed, and second being the small percentage of houses that have been verified for lead pipe presence.

The geodiversity of the cities analyzed is quite minimal as this thesis focuses only on three cities. Though they span different states, they are quite similar in their makeup. Toledo is the largest of the three cities, and Trenton is the smallest, with Flint in the middle and each different from the next by about 20,000 households. Each of the three cities has a predominantly Black population. We find that each of these three cities also had a substantial non-white population in the past, given that they were historically redlined and possessed many grade D neighborhoods. This lack of racial makeup diversity is a limitation but is also a nod to the fact that lead contamination of water is most often found in minority communities due to disinvestment. Though slightly different, all-in-all, these cities are very similar regarding relative size (none being rural and none being large metropolitan cities) and demographic makeup. Each is also a city found on the eastern side of the country. As such, this thesis is not indicative of the entire U.S., but rather is able to use these three cities as a starting point for mapping out environmental justice across the country.

The other limitation from lack of data is the small percentage of houses that have been verified of lead, a limitation most clearly seen in Toledo, OH. While Flint 63.58% of households have been checked for lead, in Toledo only 0.57% of houses have been inspected for lead pipes. This is a large difference, and thus we are less able to rely on the results gained from Toledo than the results gained from Flint due to the much smaller sample size. We saw this most clearly through the difference in the number of results that were significant between the two cities. In time, this sort of data will only grow, and this research method will be able to be applied on a more comprehensive data set to produce more accurate results. This process, however, will take time as it is costly and labor-inducive to dig up and inspect pipes at every household.

Future Research

One area of future research would be to quantitatively manipulate the data to expand the sample sizes being used. Using demographic data from the census, a model can be created to develop an estimated likelihood of lead presence in those houses that have not yet been physically verified for the presence of lead pipes in order to extend results beyond just houses that have been verified. Using this larger data set to analyze the impact of HOLC grade of lead pipe presence can hopefully produce more comprehensive results and contribute to the story that the current data is telling.

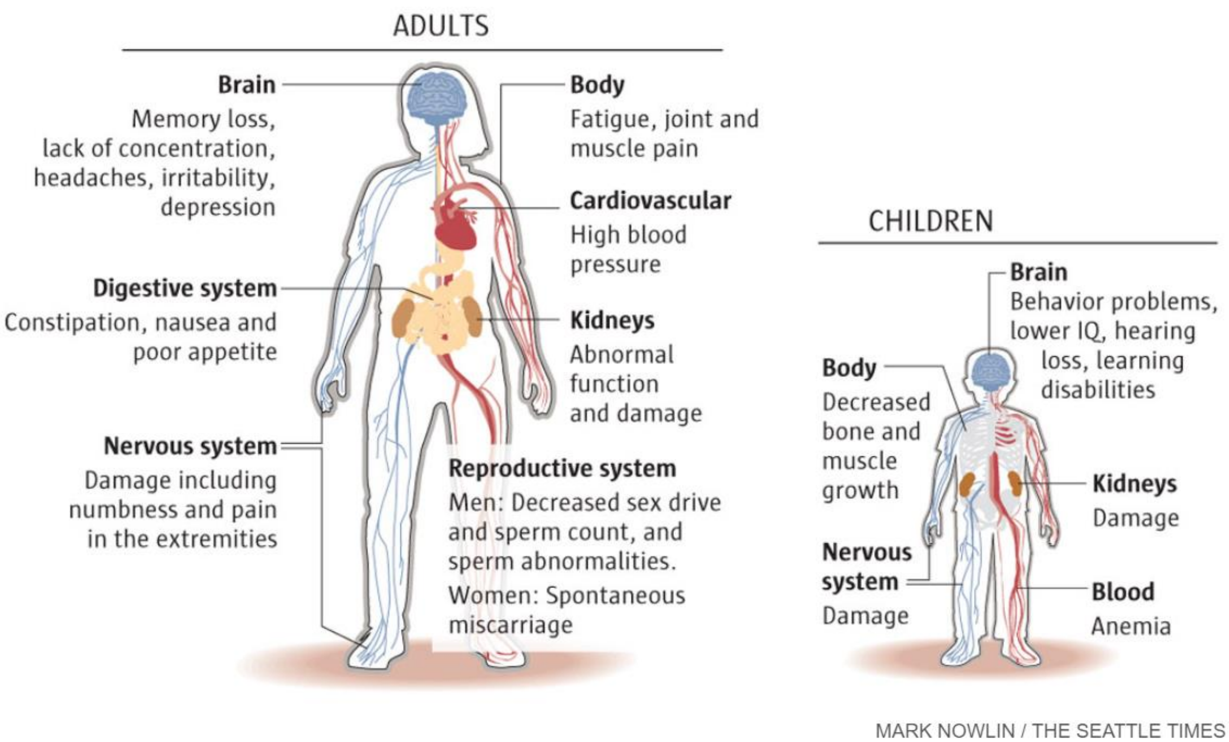
Similarly, future research also points to replicating these three studies in other cities across the nation. As explained, Flint, Toledo, and Trenton are not the most diverse and comprehensive of the U.S. population, and thus applying this study to other cities across the U.S., diversifying geographically, would allow for a better understand of the national trends with regards to each aspect of this thesis.

In regard to remediation efforts, there is a clear path to conduct further study on the makeup of the neighborhoods of focus in each city. This thesis focuses on analyzing the lead pipe presence and HOLC grade of those neighborhoods that were given priority, however, deeper analysis can be conducted to (1) better understand other factors about these neighborhoods of focus, such as demographic traits, and (2) develop a more quantitative approach to statistically determine how the neighborhoods of focus deviate from the mean of the city for each factor.

In general, the results of this thesis open an important dialogue about public policy and environmental justice. Research like this not only develops a foundation for a greater focus on understanding the past and present of a city when trying to improve the future, but it also creates the groundwork for a guide for policy makers and activist to focus their efforts.

Appendices

Appendix I: *Lead Poisoning Diagram*



Appendix II: *Lead Paint Advertisement*

Dutch Boy Painter (August 1927):117.

Appendix III: *Handwritten Index Card Records of Lead Pipes in Flint*

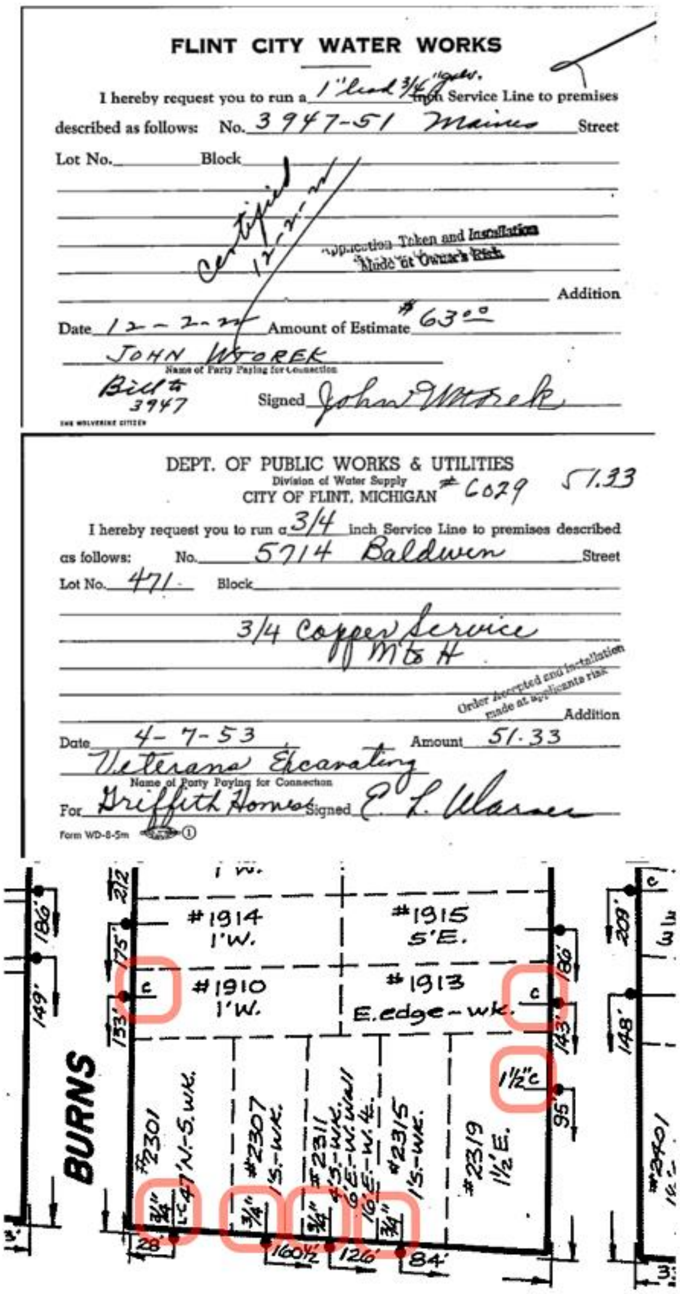


Figure 3: City officials located a set of over 100,000 handwritten index cards (top) with recorded work information dating back over 100 years, and annotated maps with data on home SLs (bottom). Red circles added to emphasize markings denoting material types.

(Abernethy et al., 2018)

__Appendix IV:__ Background – Flint Water Crisis

Though this thesis covers a variety of water crises due to lead contamination across the country, the Flint Water Crisis is often seen as the “whistleblower” event due to it being one of the first high-profile city water crises, even garnering attention from the President (McWhirter and Maher, 2016). The Flint Water Crisis was in many ways a worst-case scenario, though it is not a complete anomaly (Hobbs, 2018). For this reason, it’s important to have a clear background on the situation of the Flint Water Crisis. The Flint Water Crisis was a large catalyst for this thesis, and many similarities can be found between the Flint Water Crisis and other water crises that this thesis reviews.

Facing a looming financial crisis, in 2011 the Flint governor appointed an emergency financial manager, who remained in his position until 2015 (Kennedy, 2016). In order to address the large deficit that the city was facing, the emergency financial manager had to make a lot of budget cuts, and one of those costs cutting steps included decisions about the city’s water supply. Up until this point, Flint had used the Detroit Water and Sewage Department (DWSD) as their water provider. Flint was facing some of the highest water rates in the nation due to their aging water system, declining population, and the increasing costs of acquiring their water from the DWSD (Highsmith, 2015). Only able to readily control one of those aspect, in 2012, the idea surfaced for Flint to join the Karegnondi Water Authority (KWA). Flint would build its own pipeline connecting to the KWA, and the result would save the city $200 million over the following 25 years (Adams, 2013). In 2013, the emergency financial manager announced the decision that the city would in fact join the KWA, and that effective the following year, Flint would no longer be using the DWSD service.

As had been proclaimed, in April of 2014, the Detroit water system terminated its service to the city of Flint. However, given that the pipeline to connect the city to the KWA was still under construction and not yet operational, the city needed an interim source of water. They decided to turn to the Flint River for water, given that it had been the city’s main water source until the 1960s (Denchak, 2018). The city and state touted “numerous studies and tests conducted on its water by several independent organizations” in an effort to reassure its constituents of the quality of the water (Snyder, 2014). And thus, it was on April 25 of 2014, that water from the Flint River began to flow through the city’s pipes, and it was at the same time that the city’s service lines began to corrode. The irony in this situation, is that Mayor Dayne Walling, the mayor of Flint at the time, proclaimed that this switch was “the first step in the right direction for Flint, and we take the monumental step forward in controlling the future of our community’s most precious resource” (Kennedy, 2016). Looking back today, we know this to be farthest from the truth of what actually played out.

Even with the so-called “numerous studies and tests” that the government conducted on the Flint River water, the authorities made the decision to not immediately treat the water for corrosion control (Masten, Davies, and McElmurry 2016). The water that the city had been receiving from the City of Detroit had used corrosion control treatment, however, the water that began to be pumped through the city’s lead service lines wasn’t being treated. Though the city should have been responsible for treating the water, this decision had in fact been informed by the state’s Department of Environmental Quality, who’s officials had informed the city government that they didn’t need to (Smith and Williams, 2015). Due to the difficulty of knowing exactly how much to treatment to include given the new chemistry of the water from the river, the city decided to use what is known as the “wait-and-see” approach (Smith, 2015).

This “wait-and-see” approach, however, is not effective when the consequences of “waiting” are complete corrosion of the protective coating of the lead pipes, ultimately resulting in lead seeping into the city’s tap water and elevate blood lead levels for an entire population.

The switch to the Flint River had many unintended consequences, primarily due to the fact that the water entering the Flint pipes was now highly corrosive. Many public buildings and homes in Flint still had service lines connecting them to the municipal water system that were made of lead, and in addition to that, many households were using water fixtures that contained traces of lead (Chojnacki et al., 2017). Very quickly, Flint citizens began to complain about the perceived changes in their water quality due to the new color and smell of the water, but were wholly ignored (Bellinger, 2016). Throughout the following months, more and more studies came to light showing the harms of the municipal water supply: in August, E.coli and Total Coliform bacteria were detected prompting advisories for residents to boil their water; in October General Motors, which was originally founded in Flint, announced that it would cease using the Flint River water due to fears that the water would corrode its machines; in January of the following year, disinfection byproducts were detected (Kennedey, 2018; Denchak, 2018). After months of uncertainty and the people of Flint being discredited by their officials, in September of 2015, a team of researchers from Virginia Tech release results that indicate “serious” levels of lead in the city water (Edwards, Parks, and Mantha, 2015). The same month, a study from a local medical center found elevated lead levels in children, and the next day, Flint issued a lead advisory to its residents (Gomez, 2015).

It wasn’t until October 2015 that the city could no longer ignore extreme consequences of this decision and the water source was switched back to the DWSD (Kennedy, 2016). The Flint Water Crisis presented a disappointing display by the elected officials of the city, as they continue to attempt to minimize the scope of the problem (Bellinger, 2016). It took the concerted efforts of the entire nation to bring the attention that the situation deserved to Flint. At this point, Flint residents had already been exposed to extremely high and unsafe concentrations of lead (Pieper et al., 2018). By the start of 2016, both the Michigan Governor and the U.S. President declared a state of emergency, with the EPA issuing an emergency order. In the months that followed, houses continued to find lead contaminated water flowing out of their taps and elevate blood lead levels were found across the city. Only in April of 2018, were Flint residents given the all-clear and the city stopped providing bottled water to its residents (Baptiste, 2018). Even today, though lead levels have stabilized below the EPA’s threshold, there are still houses that use lead pipes, which keeps the door open for future hazards. Efforts to replace lead service lines were underway, however the COVID-19 pandemic presented delays, resulting in the program being approximately 85% complete prior to the outbreak (Carmody, 2020).

One of the main reasons that the Flint Water Crisis was able to get so out of hand was that the city was unable to locate their lead service lines. Without accurate knowledge of where there was the greatest probability of lead contamination, the city was unable to be strategic with selection of locations for water sampling, thus undershooting that actual water lead level (McWhirter and Maher, 2016). The city should’ve tested those houses that had lead service lines first, however, they didn’t know which houses they were. It wasn’t until 2017 that Flint was able to develop a data-centered model to map out the probability of lead contamination for each household in the city (Chojnacki et al., 2017). That is, more than 4 years after the water source switch, Flint still didn’t know where it’s lead pipes lay, despite the urgency of the situation. Thanks to studies like this one created by the University of Michigan, lead contamination mapping became possible in Flint, and soon spread to other cities that faced their own water crises (Fussell, 2021).

The Flint Water Crisis presented many researchers with a “natural experiment”. With the city limits of Flint, studies were able to be conducted comparing various different factors before and after the water lead contamination. Such studies include research on the impact of lead contamination in drinking water on economic effects, fertility, birth health, academic achievement, and student behavior (Christensen, Keiser, Lade, 2019; Grossman and Slusky, 2019; Wang, Chen, and Li, 2021; Sauve-Syed, 2018). Conversations surrounding the disproportionately negative impact on underserved and minority communities also surfaced in response to the Flint Water Crisis, continuing the conversation about environmental justice (Muhammad et al., 2018). The literature review that follows explores different studies that analyze the impact that water lead contamination had on different aspects of life, both in the context of the Flint Water Crisis, and in cities across the United States.

Appendix V: Flint Water Crisis Timeline

2011

Facing a looming financial crisis, in 2011 the Flint governor appointed an emergency financial manager, who remained in his position until 2015 (Kennedy, 2016).

Flint used the Detroit Water and Sewage Department (DWSD) as their water provider.

2012

In order to address the large deficit that the city was facing, the emergency financial manager had to make a lot of budget cuts, and one of those costs cutting steps included decisions about the city's water supply. In 2012, the idea surfaced for Flint to join the Karegnondi Water Authority (KWA). Flint would build its own pipeline connecting to the KWA, and the result would save the city $200 million over the following 25 years (Adams, 2013).

2013

In 2013, the emergency financial manager announced the decision that the city would in fact join the KWA, and that effective the following year, Flint would no longer be using the DWSD service.

2014

In April of 2014, the Detroit water system terminated its service to the city of Flint.

However, given that the pipeline to connect the city to the KWA was still under construction and not yet operational, the city needed an interim source of water. They decided to turn to the Flint River for water, given that it had been the city's main water source until the 1960s (Denchak, 2018).

The city and state touted "numerous studies and tests conducted on its water by several independent organizations" in an effort to reassure its constituents of the quality of the water (Snyder, 2014).

Thus, on April 25 of 2014, water from the Flint River began to flow through the city's pipes.

Mayor Dayne Walling, the mayor of Flint at the time, proclaimed that this switch was "the first step in the right direction for Flint, and we take the monumental step forward in controlling the future of our community's most precious resource" (Kennedy, 2016). Looking back today, we know this to be farthest from the truth of what actually played out.

The authorities made the decision to not immediately treat the water for corrosion control (Masten, Davies, and McElmurry 2016). Though the city should have been responsible for treating the water, this decision had been informed by the state's Department of Environmental Quality, who's officials had informed the city government that they didn't need to (Smith and Williams, 2015). Due to the difficulty of knowing exactly how much to treatment to include given the new chemistry of the water from the river, the city decided to use what is known as the "wait-and-see" approach (Smith, 2015).

Very quickly, Flint citizens began to complain about the perceived changes in their water quality due to the new color and smell of the water, but were wholly ignored (Bellinger, 2016).

In August, E.coli and Total Coliform bacteria were detected prompting advisories for residents to boil their water

In October General Motors, which was originally founded in Flint, announced that it would cease using the Flint River water due to fears that the water would corrode its machines

2015

In January of the following year, disinfection byproducts were detected (Kennedy, 2018; Denchak, 2018).

In September of 2015, a team of researchers from Virginia Tech release results that indicate "serious" levels of lead in the city water (Edwards, Parks, and Mantha, 2015).

The same month, a study from a local medical center found elevated lead levels in children (Gomez, 2015).

The next day, Flint issued a lead advisory to its residents

It wasn't until October 2015 that the city could no longer ignore extreme consequences of this decision and the water source was switched back to the DWSD (Kennedy, 2016). At this point, Flint residents had already been exposed to extremely high and unsafe concentrations of lead (Pieper et al., 2018).

2016

By the start of 2016, both the Michigan Governor and the U.S. President declared a state of emergency, with the EPA issuing an emergency order

In the months that followed, houses continued to find lead contaminated water flowing out of their taps and elevate blood lead levels were found across the city.

2017

The city should've tested those houses that had lead service lines first, however, they didn't know which houses they were. It wasn't until 2017 that Flint was able to develop a data-centered model to map out the probability of lead contamination for each household in the city (Chojnacki et al., 2017)

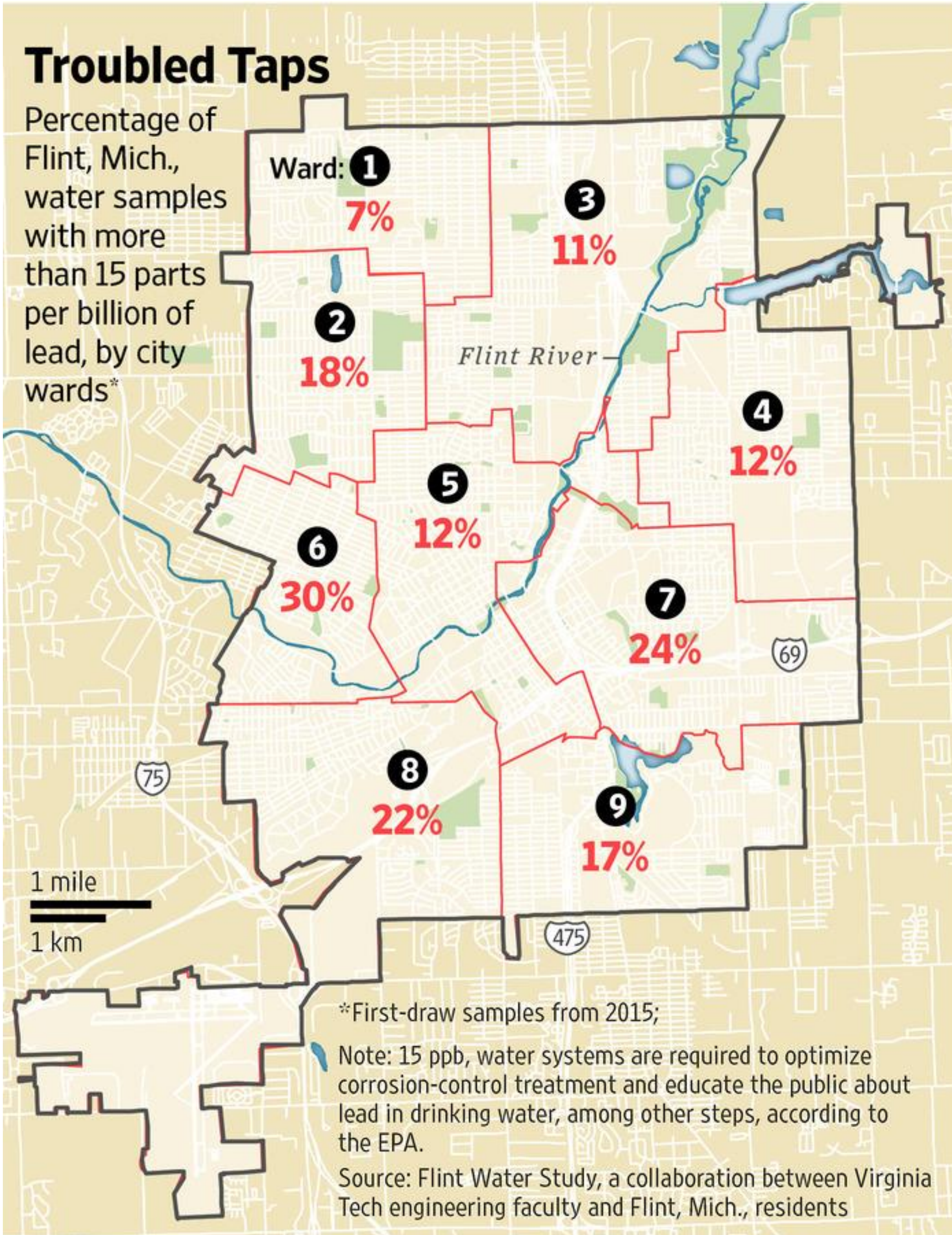
2018

Only in April of 2018, were Flint residents given the all-clear and the city stopped providing bottled water to its residents (Baptiste, 2018).).

2020

Even today, though lead levels have stabilized below the EPA's threshold, there are still houses that use lead pipes, which keeps the door open for future hazards. Efforts to replace lead service lines were underway, however the COVID-19 pandemic presented delays, resulting in the program being approximately 85% complete prior to the outbreak (Carmody, 2020).

Appendix VI: *Lead Contamination of First Water Samples in Flint, MI*



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Appendix VII: *STUDY 2 – Models for Flint*

Table 2.1.3 - Impact of Decennial Variables on Lead Presence

Dependent Variable: Lead Pipe Presence			
Independent Variables	**Coefficient**	**p value**	**Resultant Relationship**
Vacancy Household (%)	4.571006	<2e-16***	Positive
Black Household (%)	-0.533766	<2e-16***	Negative
Indigenous Household (%)	3.479988	1.14e-11 ***	Positive
Asian Household (%)	4.701827	5.27e-16 ***	Positive
Pacific Household (%)	1.882444	0.0937 .	Positive
Other-Race Household (%)	0.808600	0.0590 .	Positive
Multiple-Race Household (%)	2.418989	<2e-16***	Positive
Hispanic/Latino Household (%)	0.444759	0.0909 .	Positive
Female Householder (%)	-2.606505	<2e-16 ***	Negative
Median Age of Household	-0.009107	5.23e-15 ***	Negative

AIC: 63188

Table 2.1.4 - Impact of Race on Lead Presence

Dependent Variable: Lead Pipe Presence			
Race (White Baseline)	**Coefficient**	**p Value**	**Resultant Relationship**
Black Household (%)	-0.31904	<2e-16***	Negative
Indigenous Household (%)	4.44911	<2e-16***	Positive
Asian Household (%)	3.37921	1.96e-10 ***	Positive
Pacific Household (%)	1.78528	0.116	Positive
Other-Race Household (%)	3.54943	<2e-16***	Positive
Multiple-Race Household (%)	2.91018	<2e-16***	Positive

AIC: 67335

Table 2.1.5 - Impact of ACS (block group) Variables on Lead Presence

Dependent Variable: Lead Pipe Presence			
Independent Variable	**Coefficient**	**p value**	**Resultant Relationship**
Median Income of Household	-4.958e-6	3.68e-7 ***	Negative
Median House Value	-1.98e-5	<2e-16***	Negative

AIC: 65983

Table 2.1.6 - Impact of Decennial (block) and ACS (block group) Variables on Lead Presence

Dependent Variable: Lead Pipe Presence			
Independent Variables	**Coefficient**	**p value**	**Resultant Relationship**
Vacancy Household (%)	4.07200	<2e-16***	Positive
Black Household (%)	-0.590800	<2e-16***	Negative
Indigenous Household (%)	2.81200	4.47e-8 ***	Positive
Asian Household (%)	5.45300	<2e-16***	Positive
Pacific Household (%)	1.67900	0.14830	
Other-Race Household (%)	0.576500	0.17501	
Multiple-Race Household (%)	2.39100	<2e-16***	Positive
Hispanic/Latino Household (%)	0.09708	0.71253	
Female Householder (%)	-2.41400	<2e-16 ***	Negative
Median Age of Household	-0.003192	0.00768 **	Negative
Median Income of Household	-8.609e-6	3.22e-12 ***	Negative
Median House Value	-1.98e-5	<2e-16***	Negative

AIC: 62397

Table 2.1.1 – Statistics on Flint, MI

Total Addresses	62335	**White Households**	44.19%
Lead Verified Addresses	6569 (10.53%)	**Black Households**	51.58%
Addresses with Lead	1846 (28.38%)	**Indigenous Households**	0.55%
Addresses without Lead	4723 (71.90%)	**Asian Households**	0.45%

Total Census Households	43128	**Pacific Households**	0.02%
		Other Race Population	0.90%
		Two or more races	2.30%
		Hispanic/Latino	2.82%

Appendix VIII: *STUDY 2 – Models for Toledo*

Table 2.2.3 - Impact of Decennial Variables on Lead Presence

Dependent Variable: Lead Pipe Presence			
Independent Variables	**Coefficient**	**p value**	**Resultant Relationship**
Vacancy Household (%)	5.724e-01	0.5488	
Black Household (%)	2.221e-02	0.9372	
Indigenous Household (%)	2.667e+00	0.6340	
Asian Household (%)	-3.776e+00	0.4995	
Pacific Household (%)	-6.182e+02	0.9776	
Other-Race Household (%)	2.467e+00	0.3821	
Multiple-Race Household (%)	-5.003e+00	0.1236	
Hispanic/Latino Household (%)	0.444759	0.3469	
Female Householder (%)	-3.066e+00	0.0148 *	Negative
Median Age of Household	-1.679e-02	0.1355	

AIC: 736.32

Table 2.2.4 - Impact of Race on Lead Presence

Dependent Variable: Lead Pipe Presence			
Race (White Baseline)	**Coefficient**	**p Value**	**Resultant Relationship**
Black Household (%)	0.1596	0.5033	
Indigenous Household (%)	0.5130	0.9222	
Asian Household (%)	-2.0759	0.7064	
Pacific Household (%)	-639.7458	0.9771	
Other-Race Household (%)	1.4448	0.3420	
Multiple-Race Household (%)	-5.2738	0.0777	

AIC: 736.76

Table 2.2.5 - Impact of ACS (block group) Variables on Lead Presence

Dependent Variable: Lead Pipe Presence			
Independent Variable	**Coefficient**	**p value**	**Resultant Relationship**
Median Income of Household	-1.627e-05	0.051 .	Negative
Median House Value	-2.835e-06	0.415	

AIC: 731.24

Table 2.2.6 - Impact of Decennial (block) and ACS (block group) Variables on Lead Presence

Dependent Variable: Lead Pipe Presence			
Independent Variables	**Coefficient**	**p value**	**Resultant Relationship**
Vacancy Household (%)	-2.699e-01	0.7854	
Black Household (%)	-5.044e-01	0.1215	
Indigenous Household (%)	3.179e+00	0.5757	
Asian Household (%)	-3.714e+00	0.5191	
Pacific Household (%)	-5.979e+02	0.9775	
Other-Race Household (%)	2.681e+00	0.3504	
Multiple-Race Household (%)	-4.724e+00	0.1562	
Hispanic/Latino Household (%)	-3.430e+00	0.0950 .	Negative
Female Householder (%)	-2.321e+00	0.0723 .	Negative
Median Age of Household	-8.512e-03	0.4666	
Median Income of Household	-2.039e-05	0.0277 *	Negative
Median House Value	-6.383e-06	0.1341	

AIC: 728.28

Appendix IX - *STUDY 2 – Models for Trenton*

Table 2.1.3 - Impact of Decennial Variables on Lead Presence

Dependent Variable: Lead Pipe Presence			
Independent Variables	**Coefficient**	**p value**	**Resultant Relationship**
Vacancy Household (%)	-0.212439	0.5764	
Black Household (%)	0.338111	0.0021 **	Positive
Indigenous Household (%)	-3.170792	0.1849	
Asian Household (%)	-4.346674	2.81e-05 ***	Negative
Pacific Household (%)	2.120027	0.5823	
Other-Race Household (%)	-0.436043	0.4463	
Multiple-Race Household (%)	-0.018929	0.9832	
Hispanic/Latino Household (%)	0.444759	0.0381 *	Positive
Female Householder (%)	0.191238	0.6780	
Median Age of Household	-0.024421	2.38e-07 ***	Negative

AIC: 7643.1

Table 2.1.4 - Impact of Race on Lead Presence

Dependent Variable: Lead Pipe Presence			
Race (White Baseline)	**Coefficient**	**p Value**	**Resultant Relationship**
Black Household (%)	0.53272	4.70e-09 ***	Positive
Indigenous Household (%)	-0.93063	0.6856	
Asian Household (%)	-4.10955	7.14e-05 ***	Negative
Pacific Household (%)	3.28175	0.3898	
Other-Race Household (%)	1.46150	2.60e-07 ***	Positive
Multiple-Race Household (%)	1.36828	0.0984	

AIC: 7674.4

Table 2.1.5 - Impact of ACS (block group) Variables on Lead Presence

Dependent Variable: Lead Pipe Presence			
Independent Variable	**Coefficient**	**p value**	**Resultant Relationship**
Median Income of Household	4.338e-06	0.00882 **	Positive
Median House Value	-5.244e-06	< 2e-16 ***	Negative

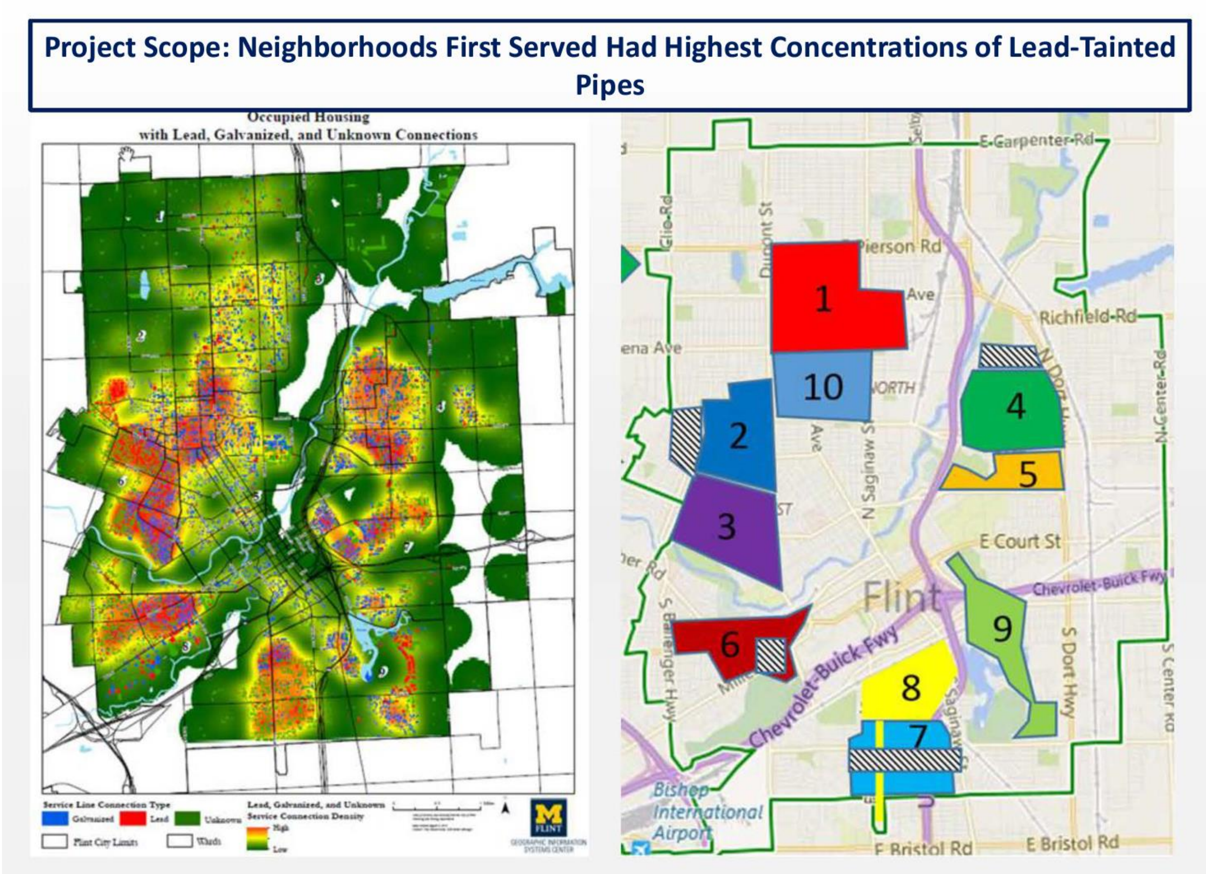
AIC: 7654.4

Table 2.1.6 - Impact of Decennial (block) and ACS (block group) Variables on Lead Presence

Dependent Variable: Lead Pipe Presence			
Independent Variables	**Coefficient**	**p value**	**Resultant Relationship**
Vacancy Household (%)	-2.728e-01	0.481405	
Black Household (%)	6.476e-02	0.636746	
Indigenous Household (%)	-3.961e+00	0.099797 .	Negative
Asian Household (%)	-3.927e+00	0.000182 ***	Negative
Pacific Household (%)	2.193e+00	0.570067	
Other-Race Household (%)	-5.036e-01	0.383406	
Multiple-Race Household (%)	-2.446e-01	0.786179	
Hispanic/Latino Household (%)	2.424e-01	0.524288	
Female Householder (%)	1.997e-01	0.666754	
Median Age of Household	-2.067e-02	1.88e-05 ***	Negative
Median Income of Household	4.966e-06	0.004098 **	Positive
Median House Value	-3.815e-06	2.88e-07 ***	Negative

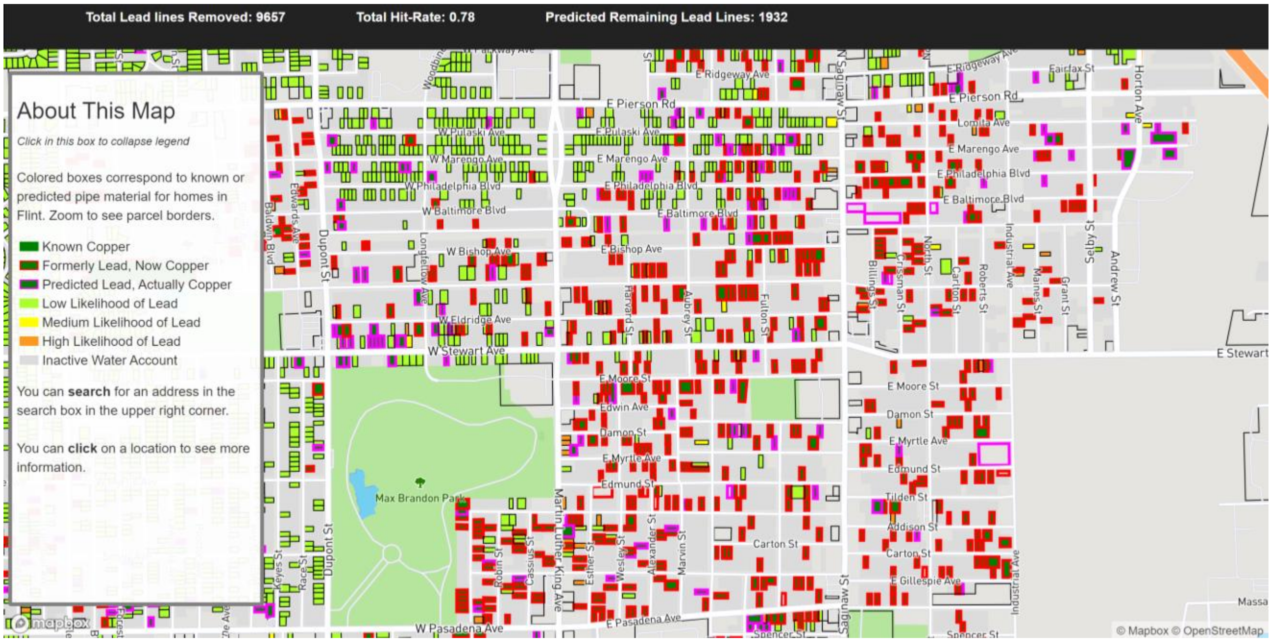
AIC: 7599.6

Appendix X- *FAST Start Program Scope (Flint)*



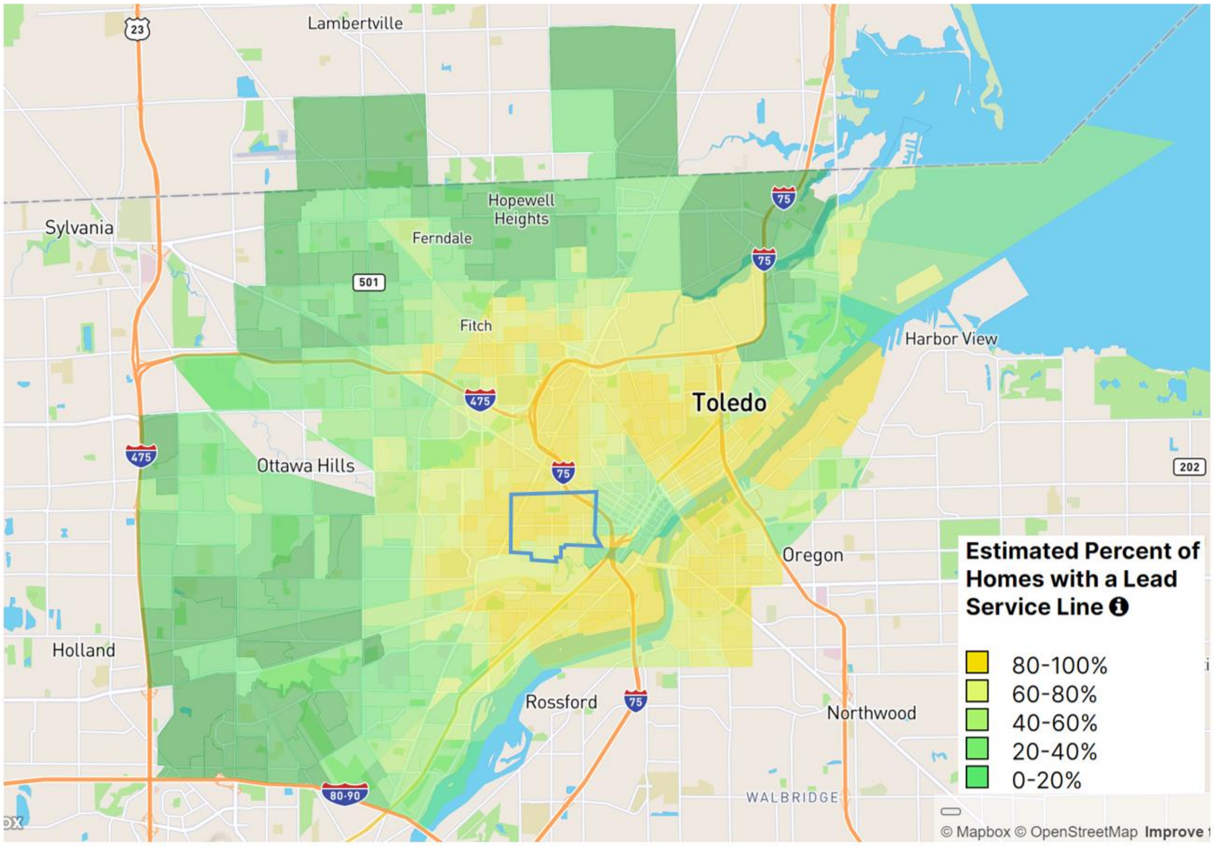
(McDaniel, 2017)

Appendix XI – *BlueConduit Flint Lead Pipe Map (partial)*



https://flintpipemap.org/probability_map

Appendix XII – *BlueConduit Toledo Lead Service Line Map, with first neighborhood focus outlined in blue*



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