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ELEVATED LEAD LEVELS IN PUBLIC DRINKING WATER SYSTEMS DESPITE GOVERNMENTAL POLICIES: FLINT, MICHIGAN CASE STUDY

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ABSTRACT: *Trust in public water systems should be obtainable given the multi-layered federal, state and local regulations and policies that address the quality of our nation's drinking water. When water borne contaminants reach alarming levels and gain national media attention, that trust is lost. This article examines the crisis in Flint, Michigan, where public health issues have escalated from lead exposure linked to contaminated drinking water. Lead exposure has long-term and irreversible effects that are difficult to quantify in sensitive populations such as children and pregnant women. The Environmental Protection Agency is responsible for establishing and enforcing policies, regulations and guidance in the development of state safe drinking water programs and policies. A literature review was conducted to identify multiple layers of governmental protection, human health impacts, chemical processes influencing lead exposure and how this incident can be seen as a case of environmental injustice. With 40% of Flint residents living in poverty, the city and its state-appointed financial emergency managers targeted the public water system for cost saving initiatives. This study found that the cause of lead exposure within drinking water was linked to a source water switch and the subsequent failure to establish a mandated corrosion control treatment program. Some ambiguity exists among the federal and state polices, but in the end, concerns of economic pressures overshadowed the requirement to protect public health.*

Keywords: *Flint, drinking water, lead levels, environmental justice*

INTRODUCTION

This article presents a case study of Flint, Michigan and the crisis involving lead exposure from municipal water. The study reveals human impacts of contaminated public water, reviews policies at multiple levels of government, provides insight into the chemical processes pertaining to lead contamination, and how this may be interpreted from the viewpoint of environmental justice. In early 2014, while under financial crisis, Flint switched its municipal water source as a cost savings initiative. By September 2015, the locally treated municipal water from the Flint River was identified as the catalyst that released harmful amounts of lead to the city's residents.

Lead is a ubiquitous, heavy metal contaminant that has been historically found in ground, air and water. At one particular site, there could be multiple lead contaminant sources such as water, dust and paint (EPA 1992). In cases involving increased water lead levels in Washington, D.C. and Flint, Michigan, studies have shown a direct relationship between water lead levels and blood lead levels (BLL) in an absence of alternative sources of lead contamination (Edwards, Triantafyllidou, and Best 2009; Brown and Margolis 2012; Hanna-Attisha et al. 2016). This article examines municipal water as the sole source of contamination, even though it is often overlooked as a primary source of lead exposure (Renner 2010).

As a neurotoxin, lead has been attributed to morbidity, loss of IQ, violence and infant mortality (Clay, Troesken, and Haines 2010; Hanna-Attisha et al. 2016). The characteristics of lead exposure make population exposure estimates difficult to quantify. Childhood lead poisoning has the ability to affect nearly all bodily systems and produce notable intelligence quotient deficiencies as well as morbidity and social behavior problems (Clay, Troesken, and Haines 2010; Hanna-Attisha et al. 2016). These symptoms can become apparent much later, after the exposure to lead has passed. Infant mortality is another area that could be misdiagnosed. Infant BLLs have been correlated to their mother's BLL, indicating the ability of lead contamination to transfer between mother and child. This is the case in pre-natal studies and in post-natal studies where maternal breast milk has also shown similar BLL (Clay, Troesken, and Haines 2010). Additional delayed effects have been documented in the ability of lead to be stored in human bones. As requirements for calcium increase with pregnancy and lactation, bone stores can release the retained lead contamination (Brown and Margolis 2012).

Historical trends have seen reductions in estimated BLL with the introduction of critical policies including the Toxic Substance Control Act of 1976 to reduce lead contaminated soils and dust as well as lead paint hazards and the Clean Air Act of 1963 to reduce lead exposure from airborne sources such as leaded fuels (EPA 2016a). Addressing water as a source of lead exposure, the Safe Drinking Water Act (SDWA) and specifically the 1991 Lead and Copper Rule (LCR) amendment, prohibited the manufacturing and installation of plumbing service lines and products containing high percentages of lead (EPA 2008, 2016b). Historical trends in U.S. lead exposure from public water have declined with the introduction of the LCR (Figure 1). While the percentage of affected U.S. children, ages 0-17, has decreased to less than one percent as of 2013, this value indicates that over 500,000 U.S. children are annually being exposed to lead in drinking water (EPA 2015a).

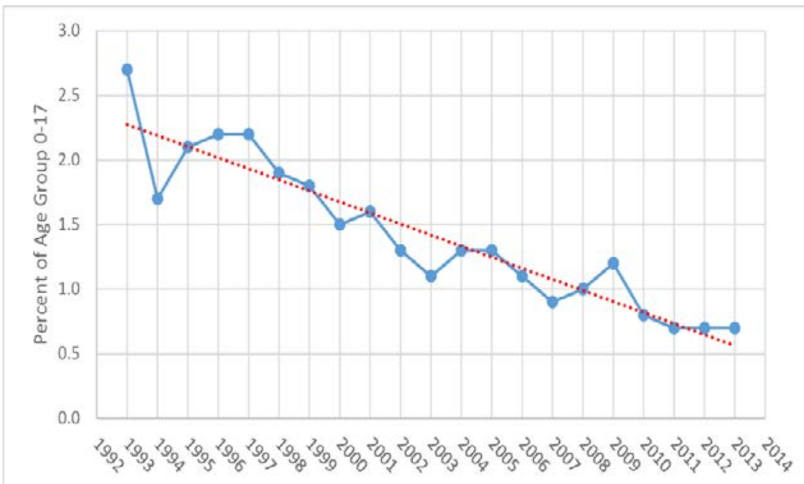

Figure 1. Estimated percentage of U.S. children < 17 years that were served by public water systems not meeting all applicable health-based drinking water standards of EPA Lead and Copper Rule from 1993-2013 (EPA 2015a).

Prior to 1970, the acceptable BLL was 60 µg/dL (micrograms per deciliter of whole blood) for children and 80 µg/dL for adults (NLM 1993). As studies on human impact of lead exposure developed, they drove a series of decreases in allowable limits, yet, determining a safe level is complicated by the variance between agencies and terms of measurements (Table 1). The EPA's lead contaminant action level for municipal water was reduced by the 1991 LCR amendment to the SDWA to water lead levels (WLL) of 15 ppb (parts per billion), well below the 1975 criterion of 50 ppb (EPA 2008; Clay, Troesken, and Haines 2010).

Table 1. Listing of past and present lead levels by agency (NLM 1993; Edwards 2010; CDC 2016)

Agency	Level	Summary
EPA	50 ppb	1975 Water Lead Level (WLL) maximum limit
EPA	15 ppb	1991 WLL requiring public notice if ≥10% of water samples exceed 15 ppb
CDC	5 µg/dL	Elevated Blood Lead Level (EBLL) term used at or above this point
CDC	10 µg/dL	Blood Lead Level (BLL) goal limit with all sources of lead involved
CDC	10 µg/dL	Pre-2012 BLL "Level of Concern" in children
CDC	2.5%	2012 BLL changed to "Exposed to lead and require case management," in age group 1-5 years, if sample is above 97.5 percentile of population
CDC	45 µg/dL	BLL unchanged for medical intervention required
PHS/NLM	60-80 µg/dL	Pre-1970 BLL maximum for child (60) and adult (80)
PHS/NLM	10 µg/dL	1990 BLL maximum blood lead level reported by Public Health Service (PHS)
PHS/NLM	20 µg/dL	BLL with medical intervention recommended by PHS

Note: Agencies listed are Environmental Protection Agency (EPA), Center for Disease Control (CDC), and Public Health Service/National Library of Medicine (PHS/NLM)

Soluble lead contained in water is absorbed disproportionately by children at 40 - 50%, while adults absorb 3 - 10% (Hanna-Attisha et al. 2016). Adult BLLs have a tendency to rise more slowly, due to a better ability to excrete lead (Clay, Troesken, and Haines 2010). When considering dose response of children less than five years, increases of 1.0 ppb in WLL will produce a 35% increase of BLL (Hanna-Attisha et al. 2016). These considerations have caused the U.S. Public Health Service (PHS) to establish 10 µg/dL as the maximum BLL threshold to protect sensitive populations, such as pregnant women and children. The PHS further states that a BLL over 20 µg/dL requires medical intervention (NLM 1993). Other direct correlations of BLL and water lead levels have been documented. In a study of infants drinking formula reconstituted by tap water with a WLL of 10 ppb, 25% exceeded the Center for Disease Control (CDC) elevated BLL of 5 µg/dL (Hanna-Attisha et al. 2016). Specific studies (Brown and Margolis 2012; EPA 2015d; Hanna-Attisha et al. 2016) and the NLM have agreed with the CDC (2016) that: "No safe blood lead level in children has been identified". In 1993, more than six million children under the age of five were reported to have BLL in excess of 10 µg/dL (NLM 1993).

FEDERAL POLICIES APPLICABLE TO THE FLINT DRINKING WATER CRISIS

Source Water Protection Policies

Several Federal policies are linked to provide safe drinking water in the U.S. (Table 2). Under the administration of the EPA, the Clean Water Act (CWA) protects source waters from point-source pollutants via the National Pollutant Discharge Elimination System (NPDES). It also requires states to determine beneficial uses for each body or section of water and to list impaired systems (MIDEQ 2014b). If a body of water is listed as impaired, a Total Maximum Daily Load (TMDL) is required to identify and rectify the cause (MIDEQ 2014b; EPA 2015b). EPA's Safe Drinking Water Act established requirements for states to develop a Source Water Assessment Program (Cox 1997; EPA 2016d). The purpose was for each state to develop an inventory of source waters considered for public water systems and to determine contaminants or susceptibility of contamination of those source waters (EPA 2016d). Additional rules have been established under the SDWA including the surface water treatment rule and the enhanced surface water treatment rule (Cox 1997; EPA 2016b), which were applicable to both raw water sources in the Flint, Michigan case study.

Table 2. Federal legislation and policies pertinent to the prevention of lead contamination in public water systems

Year	Legislation / Policy	Summary
1972	Clean Water Act (CWA)	Federal legislation applying to water pollution
1974	Safe Drinking Water Act (SDWA)	Federal law governing all aspects of public water systems (PWS)
1975	National Primary Drinking Water Regulations (NPDWR)	SDWA amendment establishing contaminants and maximum contaminant levels
1976	Primacy Regulation	SDWA amendment shifting enforcement/regulation to state
1991	Lead and Copper Rule (LCR)	SDWA amendment applying to lead concentrations and use of lead in PWS
1994	Executive Order EO-12898	Strategy to ensure environmental justice
1996	Consumer Confidence Report (CCR) Rule	SDWA amendment to inform consumers of contaminant risks in PWS
1996	Source Water Assessment Program (SWAP)	SDWA amendment to assess water bodies for purpose of PWS
1998	Disinfectant-Disinfection By-Products Rule	SDWA amendment addressing disinfectants forming unintended byproducts
2008	Short-Term Regulatory Revisions and Clarifications	SDWA- LCR revision covering sampling and public notification
2011	Reduction of Lead in Drinking Water Act	SDWA amendment further reducing lead content used in plumbing

These policies and regulations are designed to protect source waters considered for use as public water supply from point (NPDES) and point / non-point (TMDL) sources of pollutants. Lead contamination is rarely found in source waters unless a specific source of contamination is present (Brown and Margolis 2012).

Municipal water protection policies

The SDWA also provides guidance and regulatory measures to protect finished drinking water (EPA 2015d). The SDWA sets maximum contaminant level (MCL) goals for a variety of organic and inorganic contaminants listed in the EPA's National Primary Drinking Water Regulations (NPDWR) (Cox 1997). The 1991 amendment of the SDWA established the Lead and Copper Rule to address health concerns that can result in contamination of public drinking water, due to corrosion of plumbing lines and fixtures containing lead (EPA 2007a, 2009). The LCR covers a myriad of rules defining items such as: the prohibition of manufacturing and installation of plumbing materials containing high percentages of lead, sample monitoring for lead at customers' taps, defining an action level of 15 ppb in water lead levels, corrosion control treatment requirements and public notification of samples surpassing action levels (EPA 2007a, 2009). Since the establishment of the LCR, several guidelines have been issued by the EPA to further reduce exposure to lead from municipal water sources. Under the Reduction of Lead in Drinking Water Act of 2011, the EPA established regulations further reducing the percentage of lead in manufacturing and installation of plumbing fixtures that went into effect in 2014 (EPA 2016b). In the Short-Term Regulatory Revisions and Clarifications of the LCR, the EPA reinforced guidance covering minimum monitoring samples and approval requirements for water treatment changes, including changes of source water (EPA 2007a, 2015d, 2016b).

Another rule added that could be modified to apply to WLL was the Disinfectant-Disinfection By-Products (D-DBP) Rule. The rule was established to monitor total trihalomethanes (TTHM) and haloacetic acids, which are by-products of water treatment disinfectants, such as chlorine and chloramines (Cox 1997; EPA 2016b). The other by-product of disinfectants is alteration of the water chemistry that has been attributed to enhancing the corrosive capabilities in lead service lines and plumbing; thus monitoring these by-products could provide an early warning signal that lead levels may have become elevated (Schock 1989; EPA 2007b; Edwards, Triantafyllidou, and Best 2009). This is not covered in the D-DBP rule (EPA 2016b).

One change in the 1996 amendments to the SDWA was mandating water suppliers to become transparent in their service providing the "right to know" through the Consumer Confidence Report (CCR) rule (Blette 2008; EPA 2016b). The purpose of the CCR is to inform customers of water source(s), contaminants found in finished water and, if applicable, the health risks of those contaminants (Blette 2008; EPA 2016b). Some studies would disagree with the effectiveness of the CCR in getting information to the consumer (Johnson 2003; Lambrinidou 2015). In defense of the CCR rule, a Massachusetts study showed that MCL violations dropped 30% to 44% with the onset of the annual reports beginning in 1998 (Bennear and Olmstead 2008).

The EPA is responsible for establishing and enforcing drinking water standards under the SDWA to include setting MCL guidance, treatment techniques and establishing monitoring and reporting requirements (EPA 2015d). However, the EPA, through the SDWA revisions, shifted primary enforcement responsibility to the state level (Deason, Schad, and Sherk 2001). The state's primacy is hinged on developing regulations for contaminants that are "no less stringent" than those listed under the EPA's NPDWR (Blette 2008; EPA 2015c). Primacy has been under scrutiny for yielding too much discretionary authority to the states. Additional requirements of primacy involve having regulations to enforce, defining a principal lab for testing, and establishing a plan to distribute water in case of emergencies (EPA 2015c). The state of Michigan accepted primacy in 1976 (MIDEQ 2015).

THE CRISIS OF LEAD IN FLINT DRINKING WATER

The Flint, Michigan site

Flint lies within Genesee County in east-central Michigan (Figure 2). The Flint River runs through the city and the "Flint hydrologic unit" (HUC-8) watershed nearly encompasses Genesee County and extends into five neighboring counties (USGS 2003). Since 1967, the city did not use this watershed as a primary raw water source until April 2014. From 1967 to 2014, it received finished water sourced from Lake Huron and Lake St. Clair via the Detroit Water and Sewage Department (DWSD) (GCDC 2016). Genesee County also purchases water from DWSD and, in turn, supplies that water to nineteen surrounding cities and townships (Flint Township 2016; GCDC 2016).

Under the CWA, states must determine beneficial uses for all bodies of water and waterways which are then used in determining water quality standards (WQS) for supporting those uses including fisheries and public water source. Michigan's 2008 Flint River assessment documents that the river supports the use of a public water source

(MIDEQ 2014b). In addition, the SDWA amendment of 1996 requires a state to establish a source water assessment program (SWAP). Michigan established a SWAP and with assistance of the U.S. Geological Survey (USGS), completed the assessment, including the Flint River watershed in 2003 (USGS 2003; MIDEQ 2015).

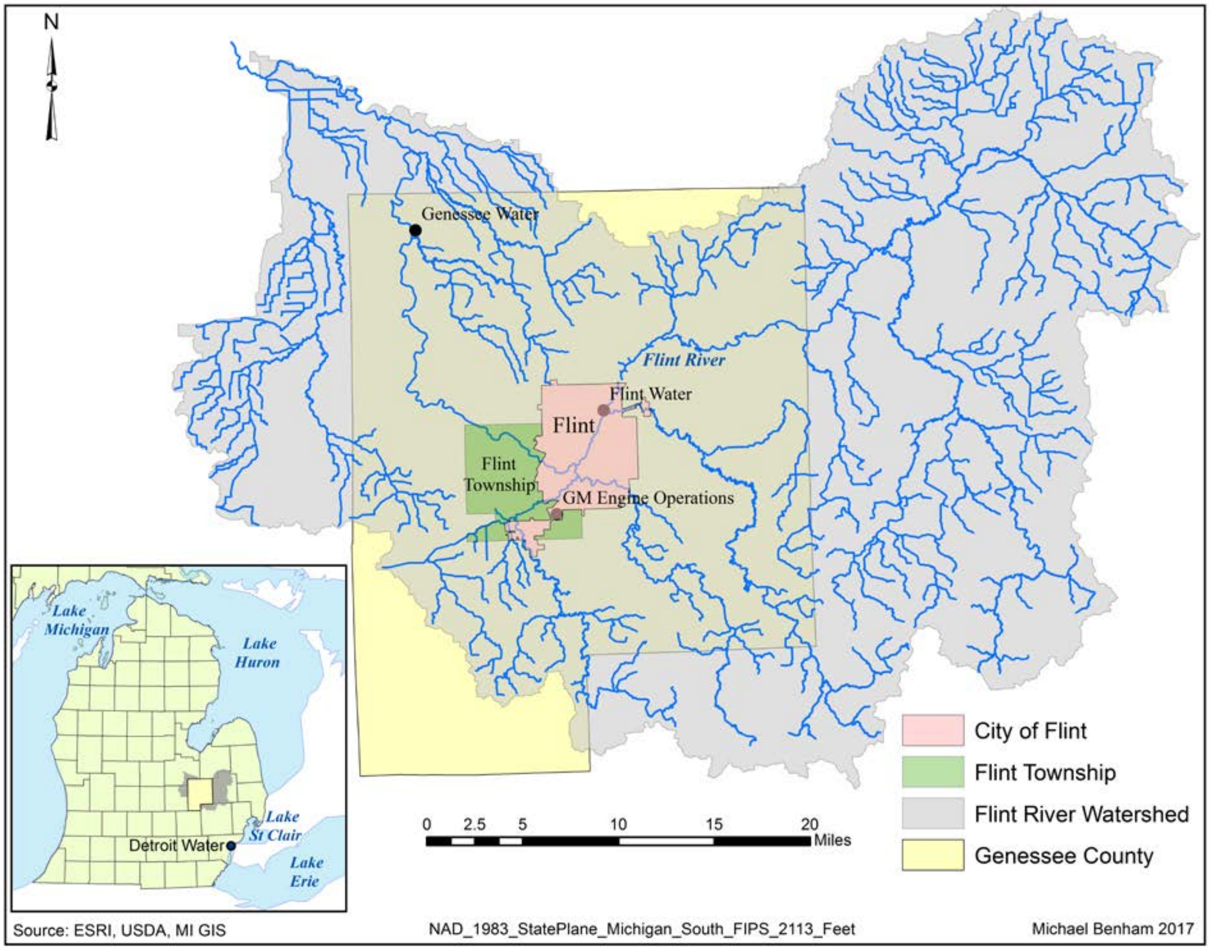

Figure 2. Map demonstrating Flint, Michigan and the Flint River watershed in surrounding area features

The U.S. Census (2015) reveals that Flint's population had dropped from 193,317 in 1970 to under 100,000 recently. A major source of the nearly 50% loss was the 1980s-1990s pull out by General Motors (GM) of all but one of their manufacturing operations. By 2011, the city of Flint had declared a state of financial emergency due to economic losses. The state of Michigan appointed an Emergency Manager to assume all matters of the city's local government (MI Department of Treasury 2011). The city stayed under emergency management until April 2015 through four different managers: Brown, Kurtz, Earley and Ambrose (Rappleye, Riordan, and Connor 2016).

The city of Flint, under emergency financial management, was looking for ways to save funds. An engineering study measured costs of several alternatives for drinking water including: continued service from DWSD, switching to Karegnondi Water Authority (KWA), switching to the Flint River as source water with treatment at the city's existing idle water treatment plant, and combinations thereof. In 2013, a decision was made to discontinue a five-decade long contract of purchasing *finished drinking water* from DWSD in favor of a new contract with KWA, which included *raw water* delivery also from Lake Huron source waters (COF 2013; MIGOV 2016). The KWA pipeline was due to be completed in 2016, some three years later. At the announcement of the decision, the DWSD gave Flint one year of continued water service into April 2014. At that time, a second decision was made to use the Flint River as an interim source until the pipeline was completed (MIGOV 2016). The approval for the interim switch to process surface water from the Flint River, as addressed in the LCR Short Term Revisions (EPA 2007a), continues to be a matter of debate. No clear documentation could be found within any office of authority to grant the approval.

The Interim Flint River Source Water Failure

Regardless of clear approval to proceed with the interim switch to the Flint River as a raw water source, the Flint water treatment plant began producing finished water from the river in April 2014 (MIGOV 2016; Rappleye, Riordan, and Connor 2016). By October 2014, GM reached an agreement with the bordering Flint Township to purchase water from them rather than the treated Flint River water (Flint Township 2016). This decision was made in light of engine assembly parts corroding from washing processes using the heavily chlorinated water from the city of Flint. This would produce an additional $400,000 of economic loss for the city (Fonger 2014). This maneuver by GM should have alerted the city to serious problems with the treatment practices and lack of an optimal corrosion control process in finished drinking water.

The EPA requires the public water suppliers to perform monitoring of water quality at the tap. The EPA also requires action and public notice when 10% of samples are above the action level for WLL of 15 ppb (EPA 2008). The city of Flint water quality reports indicate that samples are currently taken at ten sites every two to three weeks with over 100 tests per month (COF 2014). A separate study demonstrated that to effectively capture incidents at a 20% rate would require at least 225 samples, and that number would be larger to capture at a 10% level with confidence (Schock, Levin, and Cox 1988). There is difficulty in collecting accurate data, diagnosing lead poisoning, and quantifying the effects of low-dose exposure of soluble lead contaminants. Those difficulties, along with the irreversible and life altering implications, should put exposure elimination at the highest concern (Hanna-Attisha et al. 2016).

The city had ramped up chlorination due to three violations of the total coliform rule (TCR) in August and September 2014 (EPA 2009, 2016c). This was followed by a violation of TTHM in October through December 2014 (MIDEQ 2014a). High TTHM is a common by-product in additions of disinfectants like chlorine or chloramine (Cox 1997). The abundance of chlorination within the finished water was instrumental in affecting water chemistry and its ability to subsequently leach lead from service lines into customers' homes (EPA 2007b; Edwards, Triantafyllidou, and Best 2009). Dr. Hanna-Attisha's study demonstrated BLLs increased in Flint 2.4 - 4.9% over the city with a single neighborhood maximum of 6.6% during the recent crisis. These elevated lead levels, measured against past CDC mandated screenings of children 1 to 2 years of age under Medicaid, demonstrated that the incident occurred solely within the city of Flint and not in the surrounding areas. The analysis provided a definitive link to the public water supply as the source of the increase (Hanna-Attisha et al. 2016). The missing link was the absence of an optimal corrosion control program mandated by the LCR (EPA 2007a, 2009).

Chemical Nature of Lead Solubility

The concern of plumbosolvency (the ability of water to act as a solvent to dissolve lead) becomes imminent as finished water from a treatment facility flows through distribution of lead service lines, or older household plumbing and fixtures with lead-based solder. A common source of exposure to lead poisoning lies within the lead service lines, plumbing practices used in the past, and the water chemistry that affects them (EPA 2007b; Edwards, Triantafyllidou, and Best 2009; Brown and Margolis 2012; Hanna-Attisha et al. 2016). Plumbosolvency is affected by various changes to water chemistry such as pH adjustment, alkalinity, temperature, standing time and additions of chemicals induced during finished water processing (Schock and Gardels 1983; Schock 1989; EPA 2007b; Renner 2010). Alkalinity and pH adjustments can also affect the dissolved inorganic carbonate (DIC) concentration (Schock 1989). The level of DIC is critical in the formation of lead carbonate protective films within lead service lines which inhibit plumbosolvency. Finished water with low pH can trigger a breakdown of lead carbonate coatings and the subsequent release of soluble or particulate lead. The actual values of pH vary according to the input of corrosion control and other additives to finished water (Schock and Gardels 1983; Schock 1989; EPA 2007b; Renner 2010).

A starting point for utilities distributing finished water using strictly pH adjustments should be at a minimum pH of 8.5 (Schock 1989). Additions of carbonates or orthophosphates can further lower plumbosolvency. Even after the establishment of an effective lead solubility control program, additions of chemicals introduced to the finished water can produce a chain reaction in water chemistry to trigger a soluble lead release. Such was the case within Washington, D.C. in 2000 (EPA 2007b; Edwards, Triantafyllidou, and Best 2009). Other methods of capturing metal contaminants are more useful at the tap to eliminate soluble lead released through distribution. One method is utilizing granular limestone at the point-of-use, which was shown to effectively reduce lead from concentration of 3 ppm (parts per million) to below detection levels (Davis, Dixon, and Sorensen 2006; EPA 2015d).

ENVIRONMENTAL JUSTICE CONCERNS

Environmental injustice has been widely recognized since 1978, when for the first time in American history, protestors were arrested over placement of a waste facility in Warren County, NC (Chu 2006). The event sparked an investigation by the U.S. Government Accountability Office finding that three of the four landfill sites were located in predominantly black communities, although only 20% of the region's population was black. The events in North Carolina were the prelude to the United Church of Christ Commission for Racial Justice publishing the book *Toxic Wastes and Race in the U.S.* (Chu 2006). Soon after in 1979, the first lawsuit, *Bean v. Southwestern Waste Management, Inc.*, was filed in Houston to challenge the placement of 80% of the landfill and incinerator locations in black neighborhoods. Once again, the black population was only 25% of the city's total population (Bullard and Johnson 2000). As industries left Flint in the 1970-1990s, much of the population left with them. This created lower drinking water demands and steadily increasing capital costs in maintenance of infrastructure to be paid for by the remaining low income residents (Butts and Gasteyer 2011).

Environmental Justice Policies

In July 1990, the EPA established the Environmental Equity Workgroup to investigate reports of environmental justice concerns. In 1992, that workgroup reported findings to the EPA of a disproportionate rate of exposure to lead, select air pollutants and waste facility locations near groups of racial minorities and or low income. One key finding was that even at the same economic levels, black children have "unequivocally" higher blood lead levels than white children (EPA 1992). Medicaid has a policy requirement to test for blood lead levels in children as a standard part of that insurance (Hanna-Attisha et al. 2016). Although the requirement existed, an estimated 557,000 underprivileged children in California went without screening. This prompted a lawsuit against Medicaid brought forth by the National Resources Defense Council, American Civil Liberties Union, and others. The case of *Matthews v. Coye* was settled out of court for $15 - 20 million (Bullard 1994).

In 1994, President Clinton signed Executive Order 12898 (EO 1994), which tasks each federal agency to investigate, develop and maintain a strategy to ensure environmental justice for minority or low-income populations. It also provided administrative authority to the EPA in assembling and maintaining an Interagency Working Group on Environmental Justice (EO 1994). The EPA began its action on a regulation already within its control, the National Environmental Policy Act of 1970. The EPA used the Environmental Impact Statement as a means to address any Federal environmental action, which then also required research into pre-existing or future impact on minority or low income populations (EPA 1998). Despite these policies, regulations, best management practices and executive orders, incidences of environmental injustice are still arising (Edwards, Triantafyllidou, and Best 2009). Such is the case of the lead exposure found in Flint.

A comparison was made between national poverty levels and those of the city of Flint (U.S. Census 2015). Table 3 demonstrates the concentration and density of low income residents within the city. These residents existing below poverty standards are less likely to afford bottled water, faucet filters or lawyers to take their concerns to litigation. A second comparison was made addressing minority populations. Flint's demographics show a 60% minority population (non-white) (U.S. Census 2015). Flint is a clear case of environmental injustice as E.O. 12898 states that federal agency strategies will consist of efforts to "promote enforcement of all health and environmental statutes in areas with minority populations and low-income populations" (EO 1994). In the 2008 Congressional Report 110-498, the Office of the Inspector General stated the EPA has not fully implemented E.O. 12898 into it operations. In the same report, the Government Accountability Office, stated the EPA "failed to consistently consider environmental justice" in its rule-making processes.

Table 3. Comparison of poverty levels between national statistics (U.S.) and the city of Flint, Michigan

2010-2014 U.S. Census estimates	U.S.	Flint, Michigan
Population	318,907,401	99,002
Persons in Poverty (%)	15.6%	41.6%
Poverty Density (persons / mi^2)	13	1248

A dismissiveness in elevating the crisis is identified in a timeline and lack of actions taken by the state and local government (Edwards 2016; MIGOV 2016). Within months of the April 2014 switch to Flint River as a primary source of municipal water, customers had mounted complaints of color, odor and taste of the public water. These complaints culminated into a protest held in January 2015 outside of city offices. By April 2015, EPA and MIDEQ had knowledge of extremely high WLL, averaging 242 µg/dL, taken from samples of homes within Flint. It was not until October 2016, that state officials acknowledged the crisis and switched the primary water source back to Lake

Huron water from DWSD (Edwards 2016; MIGOV 2016). The state declared a state of emergency and requested Federal assistance on January 5, 2017. At least six months of lead contaminated municipal water flowed to the residents of Flint with local, state and federal government agencies having knowledge of the crisis occurring in a low-income and minority population.

Risk Assessment of Housing Age Characteristics

A concentration analysis of housing age for the state of Michigan (Figure 3) can be accomplished with data from the U.S. Census (2014). Two policies that affect potential risk of lead exposure with regard to age of housing are the Toxic Substance Control Act of 1976, which prohibited lead paints, and the Safe Drinking Water Act, which since 1986 has prohibited the use of plumbing that is not lead free (EPA 2015d, 2016a). The U.S. Census data defines housing age in even decades, but decadal maps are still useful in considering risk assessment, showing: (A) pre-1980 housing concentration, at the greatest risk of both lead paint and lead plumbing hazards, and (B) post-1980 housing with little risk of lead paint but some risk of lead plumbing and lead solder. In Genesee County, the portion of pre-1980 housing was 71%, while the state average was 66%. Although these maps tend to mirror population densities, they also identify concentrations of high risk housing in south east Michigan, which includes the city of Flint. These types of spatial analysis could be useful for local and state governments to increase vigilance on corrosion control methods in high density / high risk residential areas.

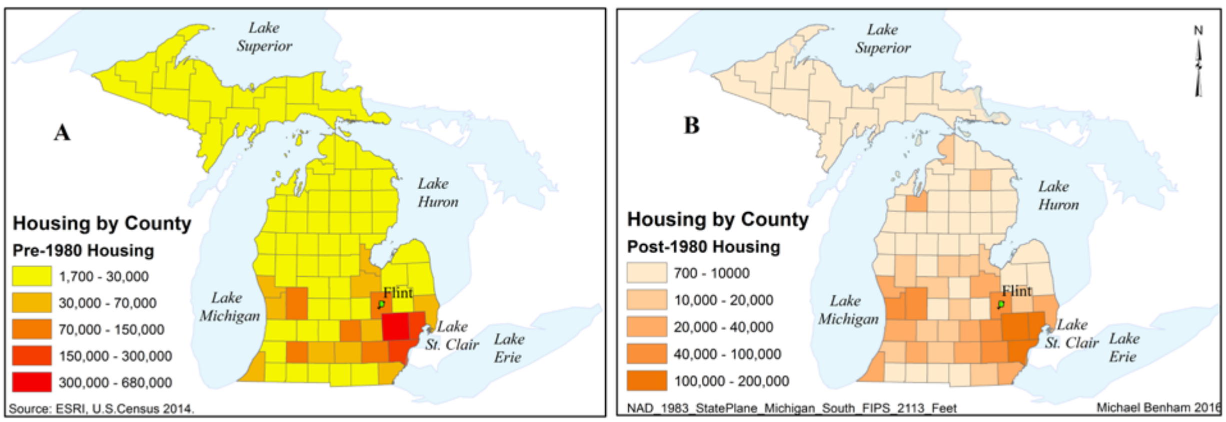

Figure 3. Housing construction eras of concern with (A) pre-1980 with higher risk of lead hazards, and (B) post 1980 with decreased risk of lead hazards, according to implementation dates of EPA Lead and Copper Rule (U.S. Census 2014; EPA 2015d).

CONCLUSION

U.S. residents expect that our drinking water is fit for consumption. Public trust in the nation's drinking water is waning in light of national news stories about risks of lead and other contaminants. The public trust must reach not only the wealthy, but also to those in poverty. Public trust should rise above any form of discrimination or environmental injustice. Lead is a persistent toxin that affects the nation's children as a sensitive population. The extent of those effects will not be seen for many years. With many sources of lead either eliminated (leaded fuels) or stringently addressed (lead paint), the nation should focus on drinking water as a key source of lead exposure. The incomplete knowledge of lead service lines used in distribution of water, requires development of location cataloging into a national open dataset for full replacement. Until then, enforcement of existing requirements for corrosion control treatments needs to be expanded to include best management practices. Primacy given to the states is necessary due to constitutional considerations. However, the EPA should not hesitate to step in to ensure that states are upholding their primary enforcement duty. Citizens depend on EPA oversight for public drinking water safety. Many other cities, such as Portland, Oregon; Providence, Rhode Island; Durham, North Carolina; and Washington, D.C., experienced similar health risks from unnecessary lead exposure (Lambrinidou 2015). These incidences demonstrate that current policies need improvement.

This article examined Flint's drinking water lead contamination crisis, where the release of soluble lead from the distribution system was shown to have caused severe health risks to public water consumers. The most probable cause is that the city did not adopt a proper corrosion control treatment program, following a switch of source water to the Flint River. The state of Michigan, as well as the city of Flint, made public water supply decisions based on economic grounds above concerns for public health. Those decisions, under the immediate supervision of state-appointed emergency managers, failed in many ways: (1) Failure to get authority to switch the raw water source, as mandated by the SDWA and LCR; (2) Failure to establish a corrosion control treatment program mandated by the SDWA and LCR; (3) Breach of primacy in reporting proper corrosion control treatment program to EPA; (4) Failure to uphold environmental justice under Executive Order 12898; (5) Failure to accept legitimate customer complaints.

The actions of Flint and the state of Michigan, whether accidental or intentional due to budget constraints, will be addressed through the court system, which has already begun to address specific faults and policy shortfalls (NRDC 2015). Policy considerations to reduce the risk of future public exposure to lead in drinking water include: (1) That all states should be required to annually submit to the EPA, reports on corrosion control treatment; (2) That all states should be required to submit to the EPA, high risk housing area surveys; (3) That all public water system plant operators should be required to undergo certification training on adverse health conditions arising from drinking water contamination. The cost of these measures would likely be less than litigation costs facing Flint and the state of Michigan.

REFERENCES

Bennear, L. S., and Olmstead, S. M. 2008. The impacts of the “right to know”: Information disclosure and the violation of drinking water standards. *Journal of Environmental Economics and Management.* 56(2):117–130.

Blette, V. 2008. Drinking water public right-to-know requirements in the United States. *Journal of Water and Health.* 6(S1):43-51.

Brown, M. J., and Margolis, S. 2012. Lead in drinking water and human blood lead levels in the United States. http://www.cdc.gov/mmwr/preview/mmwrhtml/su6104a1.htm. (Accessed February 14, 2016).

Bullard, R. D. 1994. Overcoming racism in environmental decisionmaking. *Environment: Science and Policy for Sustainable Development.* 36(4):10-44.

Bullard, R. D., and Johnson, G. S. 2000. Environmentalism and public policy: Environmental justice: Grassroots activism and its impact on public policy decision making. *Journal of Social Issues.* 56(3):555–578.

Butts, R., and Gasteyer, S. 2011. Environmental reviews & case studies: More cost per drop: water rates, structural inequality, and race in the United States—The case of Michigan. *Environmental Practice.* 13(04):386–395.

Chu, H. A. 2006. Achieving environmental justice in North Carolina public participation policies. http://cwfnc.org/documents/Environmental-Justice-through-Public-Participation.pdf. (Accessed February 1, 2016).

City of Flint [COF]. 2013. Water supply assessment. http://mediad.publicbroadcasting.net/p/michigan/files/201512/water_report.pdf. (Accessed March 10, 2016).

—. 2014. Annual water quality report. https://www.cityofflint.com/wp-content/uploads/ccr-2014.pdf. (Accessed March 4, 2016).

Clay, K., Troesken, W., and Haines, M. R. 2010. National Bureau of Economic Research. Lead, mortality, and productivity. https://core.ac.uk/download/files/153/6544873.pdf. (Accessed February 2, 2016).

Cox, W. E. 1997. Evolution of the Safe Drinking Water Act: A search for effective quality assurance strategies and workable concepts of federalism. *Wm. & Mary. Environmental Law & Policy Review.* 21(1997):69.

Davis, A. D. 2006. Development of an agglomeration process to increase the efficiency of limestone-based material to remove metals from drinking water. PhD dissertation. South Dakota School of Mines and Technology. 2006.

Deason, J. 2001. Water policy in the United States: A perspective. *Water Policy*. 3(3):175–192.

Edwards, M. 2010. Flint water study. http://flintwaterstudy.org/wp-content/uploads/2016/02/Appendix-B.pdf. (Accessed February 1, 2016).

—. 2016. Flint water study. Timeline. http://flintwaterstudy.org. (Accessed February 1, 2016).

Edwards, M., Triantafyllidou, S., and Best, D. 2009. Elevated blood lead in young children due to lead-contaminated drinking water: Washington, DC, 2001−2004. *Environmental Science & Technology Environ. Sci. Technol.* 43(5):1618–1623.

ESRI. 2015. ESRI Data and maps, *ArcGIS build 10.3.0.4322, vintage 2010*, 1:250,000.

Executive Order 12898, [EO]. 1994. Federal actions to address environmental justice in minority populations and low-income populations: executive order 12898. *Federal Register*. 59(32):7629-7633. https://www.archives.gov/federal-register/executive-orders/pdf/12898.pdf. (Accessed February 17, 2016).

Flint Township. 2016. Notice to township. http://flinttownship.org/Default.aspx?tabid=3626&Search=drinking+water. (Accessed March 10, 2016).

Fonger, R. 2014. GM shutting off Flint River water at engine plant over corrosion worries. Michigan Live http://www.mlive.com/news/flint/index.ssf/2014/10/gms_decision_to_stop_using_fli.html. (Accessed March 12, 2016).

Genesee County Drain Commissioner [GCDC]. 2016. Water and waste services report. http://www.gcdcwws.com/pages/About-Us. (Accessed March 12, 2016).

Hanna-Attisha, M., LaChance, J., Sadler, R. C., and Champney, S. A. 2016. Elevated blood lead levels in children associated with the Flint drinking water crisis: A spatial analysis of risk and public health response. *American Journal of Public Health*. 2016(0):e1-e8.

Johnson, B. B. 2003. Customer reaction to hypothetical and actual CCRs and related information. *Journal of American Water Works Association*. 95(8):90-99.

Lambrinidou, Y. 2015. Dissent to National Drinking Water Advisory Council. http://www.epa.gov/sites/production/files/2015-11/documents/ndwaclcrstatementofdissent.pdf. (Accessed February 2, 2016).

Michigan Department of Environmental Quality, [MIDEQ]. 2014a. City of Flint violation notice: MCL-TTHM. Notification of violation letter to City of Flint. https://www.cityofflint.com/wp-content/uploads/City-of-Flint-Violation-Notice-MCL-TTHM-12_16_14.pdf. (Accessed February 2, 2016).

—. 2014b. Water quality and pollution control in Michigan 2014 sections 303(d), 305(b), and 314 integrated report. http://cdm16110.contentdm.oclc.org/cdm/ref/collection/p9006coll4/id/169239. (Accessed March 4, 2016).

—. 2015. MI Safe Drinking Water Act 1976 PA 399, as amended, MCL §§325.1001 to 325.1023 and the administrative rules, supplying water to the public R 325.10101 to R 325.12820. MI Legislature.

Michigan Department of Treasury. 2011. Treasury contract letters of Emergency Managers. https://www.michigan.gov/documents/treasury/Brown_Contract_369897_7.pdf. (Accessed March 4, 2016).

Michigan GIS Open Data Portal. 2005. *Framework, WEBMERC.POL_PY_CGI_COUNTY_V15*, 1: 24,000. Michigan Resource Information System http://gis.michigan.opendata.arcgis.com/datasets/67a8ff23b5f54f15b7133b8c30981441_0.

Michigan State Government: Office of Governor [MIGOV]. 2016. Synder: Documented timeline of Flint. http://www.michigan.gov/documents/snyder/FlintWaterTimeline_FINAL_511424_7.pdf?20160119192241. (Accessed March 10, 2016).

—. 2016. Office of Governor [MIGOV]. 2016. Flint Water Advisory Task Force final report. https://www.michigan.gov/documents/snyder/FWATF_FINAL_REPORT_21March2016_517805_7.pdf. (Accessed March 18, 2017).

Natural Resources Defense Council [NRDC]. 2015. NRDC and ACLU lawsuit filing: Residents of Flint, Michigan to sue city, state of Michigan. http://www.nrdc.org/media/2015/151116.asp. (Accessed February 2, 2016).

Rappleye, H., Riordan, S., and Connor, T. 2016. Bad decisions, broken promises: A timeline of the Flint water crisis. http://www.nbcnews.com/news/us-news/bad-decisions-broken-promises-timeline-flint-water-crisis-n499641. (Accessed March 10, 2016).

Renner, R. 2010. Exposure on tap: Drinking water as an overlooked source of lead. *Environmental Health Perspective*. 118(2):A68-A72.

Schock, M. R. 1989. Understanding corrosion control strategies for lead. *Journal of American Water Works Association*. 81(7):88-100.

Schock, M. R., Levin, R., and Cox, D. C. 1988. The significance of sources of temporal variability of lead corrosion evaluation and monitoring program design. *Journal of American Water Works Association*. 1988:729-745.

Schock, M. R., and Gardels, M. C. 1983. Plumbosolvency reduction by high pH and low carbonate—solubility relationships. *Journal of American Water Works Association*. 75(2):87-91.

U.S. Center for Disease Control, [CDC]. 2016. Blood levels in children—fact sheet. http://www.cdc.gov/nceh/lead/acclpp/lead_levels_in_children_fact_sheet.pdf. (Accessed March 4, 2016).

U.S. Congress. 2008. Committee on Environment and Public Works. Environmental Justice Renewal Act hearing report, 110 Congress, 2nd session. https://www.congress.gov/110/crpt/srpt498/CRPT-110srpt498.pdf. (Accessed March 14, 2017).

U.S. Department of Agriculture. 2013. *8 Digit Watershed Boundary Dataset*, 1:24,000. National Geospatial Management Center. http://gis.michigan.opendata.arcgis.com/datasets/04966a515fd3413c8b9ab36376466748_21.

U.S. Department of Commerce, U.S. Census Bureau, [U.S. Census]. 2014. American fact finder, Flint City, Michigan. http://factfinder.census.gov/. (Accessed February 2, 2016).

—. 2015. American community survey: Housing characteristics. http://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml. (Accessed February 2, 2016).

U.S. Environmental Protection Agency, [EPA]. 1992. Environmental equity: Reducing risk for all communities. http://www3.epa.gov/environmentaljustice/resources/reports/annual-project-reports/reducing_risk_com_vol1.pdf. (Accessed February 18, 2016).

—. 1998. Final guidance for incorporating environmental justice concerns in EPA's NEPA compliance analyses. http://www3.epa.gov/environmentaljustice/resources/policy/ej_guidance_nepa_epa0498.pdf. (Accessed February 18, 2016).

—. 2007a. Lead and Copper Rule: Short term revisions and clarifications. https://www.gpo.gov/fdsys/pkg/FR-2007-10-10/pdf/E7-19432.pdf. (Accessed March 10, 2016).

—. 2007b. Elevated lead in D.C. drinking water—A study of potential causative events, final summary report. https://www.dcwater.com/lead/epa_summary_report_elevated_lead_august_2007.pdf. (Accessed March 4, 2016).

—. 2009. 2009 drinking water enforcement response policy. EPA inter-agency correspondence. http://www.epa.gov/sites/production/files/documents/drinking_water_erp_2009.pdf. (Accessed 02 February 2016).

—. 2015a. America's children and the environment. Third ed. Appendix A: Data Table 2013. http://www.epa.gov/sites/production/files/2015-10/documents/enviro-contam_drinking_water_data_tables.pdf. (Accessed February 2, 2016).

—. 2015b. History of the Clean Water Act. https://www.epa.gov/laws-regulations/history-clean-water-act. (Accessed February 2, 2016).

—. 2015c. EPA Primary enforcement responsibilities for public water systems. https://www.epa.gov/dwreginfo/primacy-enforcement-responsibility-public-water-systems. (Accessed March 10, 2016).

—. 2015d. Summary of the Safe Drinking Water Act. http://www.epa.gov/laws-regulations/summary-safe-drinking-water-act. (Accessed February 2, 2016).

—. 2016a. Lead homepage. http://www.epa.gov/lead. (Accessed March 2, 2016).

—. 2016b. Control of lead and copper. http://www.ecfr.gov/cgi-bin/text-idx?SID=531617f923c3de2cbf5d12ae4663f56d&mc =true&node=sp40.23.141.i&rgn=div6. (Accessed October 10, 2016).

—. 2016c. EPA Safe drinking water information system. https://oaspub.epa.gov/enviro/sdw_report_v3.first_table?pws_id=MI0002310&state=MI&source= Surface%20water&population=99763&sys_num=0. (Accessed March 12, 2016).

—. 2016d. Source water assessment program. https://www3.epa.gov/region1/eco/drinkwater/pc_sourcewater_assessment.html. (Accessed March 4, 2016).

U.S. Geological Survey [USGS]. 2003. The Michigan source-water assessment program. http://pubs.usgs.gov/wri/2003/4134/report.pdf. (Accessed March 12, 2016).

U.S. National Library of Medicine [NLM], National Center for Biotechnology Information, National Academy of Sciences. 1993. Measuring lead exposure in infants, children, and other sensitive populations. http://www.ncbi.nlm.nih.gov/books/NBK236458/pdf/Bookshelf_NBK236458.pdf. (Accessed February 2, 2016).