Blood Lead Surveillance for Flint Adults: January 2010-October 2017

Michigan State University
Department of Medicine

Kenneth D. Rosenman, MD

Michigan Department of Health and Human Services
Division of Environmental Health

Martha Stanbury, MSPH

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Thomas Largo, RoseAnn Miller, and Veronica Tijerina
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Joanna Kica, Janine Keck, and Peg Largo

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EXECUTIVE SUMMARY

A program for public health surveillance for adults with exposure to lead was established in 1998 in Michigan, when regulations went into effect requiring clinical laboratory reporting of all blood lead test results to the State. Until late 2015, most of the concern about lead exposure in adults had been associated with exposure at work. In late 2015, Genesee County declared a state of emergency because a drinking water supply change for the city of Flint in April 2014 had resulted in lead leaching from pipes into drinking water, resulting in increased lead exposure to individuals drinking or cooking with the water. In addition, in January 2016, public health authorities recommended that everyone in Flint have a blood lead test, resulting in a large increase in the number of adults tested. Beginning in April 2016, efforts were made to identify the source of lead exposure for all Flint adults, defined as individuals 18 years old or older, with an elevated blood lead level (EBLL), 5 micrograms per deciliter (µg/dL) or greater. This report provides data on blood lead testing of adult Flint residents from January 2010 through October 2017. The data are summarized annually and are also divided into three time periods: Period One - before the Flint water supply changed (January 2010-April 2014); Period Two - during the changed water supply (April 2014-October 2015); and Period Three - after the water supply was returned to the original source (October 2015-October 2017).

Key findings include:

- On average, in the five years preceding awareness of lead in the drinking water, about 178 adults were tested annually in Flint. After recognition of and response to lead in the drinking water, 16,343 adults were tested during the two years in Period 3, which constituted 22.3% of the estimated 73,157 population age 18 and over living in Flint.
- Between 10% and 18% of adults tested annually from 2010-2014 had EBLLs. In Period 3, 1.6% of the adults tested had an EBLL, which is the same as the estimated prevalence of adults in the US population, based on data from the National Health and Nutrition Examination Survey.
- Interviews with EBLL adults and information from providers provided information to assign or rule out lead exposure sources for 65.2%, 50.0% and 42.5% of EBLL individuals in periods 1, 2, and 3, respectively.
    - Exposure to lead at work was assigned to 73.3% (33 of 45 EBLL adults) in Period 1, 93.8% (15 of 16) in Period 2, but only 19.4% (21 of 108) in Period 3.
    - Retained bullet fragments were frequently (n=26) assigned as the exposure source in Period 3 when there was more comprehensive testing. In periods 1 and 2 combined, there was only one such case.
    - Other “traditional” sources (e.g., home renovation, indoor firing range users, hobbies) were assigned to two, zero, and four cases in Periods 1, 2, and 3, respectively.

    - No work, bullet fragments or traditional lead exposure sources were identified for one (6.3%) individual in Period 2 and 57 (52.7%) in Period 3.
        - For 54 (94.7%) of the 57 with no known lead exposure in Period 3, the individuals with EBLLs themselves or their providers attributed the exposure to drinking water.
- Eighty-eight EBLL adults who were interviewed between April 2016 and October 2017 were asked questions about water testing and use of water in their homes as of April 2014.
    - Less than half (42.1%) reported that their water had been tested.
    - Sixteen (18.2%) reported not using water filters for water from their faucets.
- Street addresses of all EBLL adults for periods 2 and 3 were matched with water testing data collected mostly in Period 3. Thirteen (21.3%) of the 61 matched addresses had at least one result exceeding the action level of 15 parts per billion lead established by the US Environmental Protection Agency.
- Fifteen street addresses also had data on testing for lead in dust, soil, and paint. Six (40.0%) of these homes had levels of lead above federal or state standards.

Based on these findings:

- Efforts should continue to encourage water filter use until lead service line replacement is completed and lead-containing faucets or plumbing are replaced in Flint.

- Additional investigation is needed to understand the magnitude and risk factors for firearm injuries in Flint so that preventive actions can be taken.

- Resources should be identified to support follow-up interviews with all EBLL adults in Flint tested since April 2014.

- Resources should be identified to support follow-up interviews with all Michigan adults with BLLs of 5 µg/dL or higher. This would provide comparison data to the data from Flint and would provide population-based data to target interventions to adults at risk of exposure to lead in communities throughout Michigan .

BACKGROUND

Blood lead levels (BLLs) of children and adults have been monitored by the State of Michigan since the 1990s. The State of Michigan health department (called the Michigan Department of Community Health until May 2015 when it was renamed the Department of Health and Human Services (MDHHS)) promulgated regulations effective October 11, 1997, that require laboratories to submit reports of all blood lead tests of children and adults to the MDHHS. Since then, the MDHHS Childhood Lead Poisoning Prevention Program (CLPPP) has received and processed all laboratory reports and maintained a surveillance system for blood lead (BL) reports of children.

Coincident with the promulgation of this regulation in 1997, Michigan received federal funding from the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC) to monitor adult BLLs as part of NIOSH's Adult Blood Lead Epidemiology and Surveillance (ABLES) program. Up to forty-one states established lead registries through the ABLES program for surveillance of adult blood lead levels.[1] Because the source of elevated blood lead in 80% of adults is occupational exposure, the focus of the ABLES program has been the identification of work-related sources of lead linked to interventions in the workplace to prevent exposures. The ABLES program in Michigan is administered by the Division of Occupational and Environmental Medicine, College of Human Medicine, Michigan State University, as a bona fide agent of the State, in collaboration with the Michigan Occupational Safety and Health Administration (MIOSHA). MDHHS CLPPP has provided laboratory reports of adults to MSU for processing into the ABLES system since 1997. Annual summary reports of ABLES data are available at www.oem.msu.edu.

A large percentage of blood lead testing in adults has been performed to meet the requirements of MIOSHA lead standards[2,3] for employee medical monitoring of individuals exposed to lead at work. The sources of lead exposure identified with non-work exposure to lead have included recreational shooting, casting and reloading of bullets, retained bullet fragments, home remodeling, and rarer exposure events such as the use of lead-contaminated pottery or ingestion of spices or other food products contaminated with lead.

Events in Flint, Michigan, beginning in April 2014, had an impact on blood lead testing and lead exposure for adults and children living in Flint.[4] In April 2014, water for the city of Flint was changed from the Detroit Water and Sewerage Department (DWSD), sourced from Lake Huron, to the Flint Water System (FWS), sourced from the Flint River. The different characteristics of the water and lack of corrosion control chemicals resulted in leaching of lead from pipes in the city's water infrastructure into the water supply. Increased water lead levels and elevated blood lead levels in young children were observed in Flint in September 2015 and confirmed by the Centers for Disease Control and Prevention in July 2016. [5,6,7] The source of drinking water for Flint was switched back to the DWSD in October of 2015.

Emergency declarations were issued by Genesee County in October 2015, and the State of Michigan and the federal government in January 2016. The public health emergency brought local, state, and federal resources to coordinate a response that included a recommendation that all Flint residents receive blood lead testing. In addition, MDHHS contracted with Michigan State University to provide follow-up to individuals with elevated blood lead levels, with follow-up to children through age 17 provided by the Greater Flint Health Coalition and follow-up to adults age 18 and older provided by Michigan State University.

This report summarizes surveillance data on Flint residents age 18 and older from January 1, 2010 through October 31, 2017, with a focus on the data for individuals tested since April 2014, when the water source changed to the FWS.

METHODS

Reporting Regulations and Mechanism

Since October 11, 1997, laboratories performing blood lead analyses have been required to report the results of all blood lead tests to the MDHHS [Michigan Compiled Laws 333.5474(c) and Michigan Administrative Code R 325.9081- 325.9086].

The clinical laboratories conducting business in Michigan that analyze blood samples for lead are required to report blood sample analysis results, patient demographics, and, for adults, employer information electronically to the MDHHS CLPPP within five working days. The healthcare provider ordering the blood lead analysis is responsible for completing the patient information, the physician/provider information, and the specimen collection information. Upon receipt of the blood sample for lead analysis, the clinical laboratory is responsible for completion of the laboratory information.

Data Collection/Management

The MDHHS CLPPP forwards the electronic record of all blood lead results on individuals 16 years or older to the ABLES program at Michigan State University. ABLES defines an “adult” as age 16 and above because ABLES focuses on work exposure and teens can work at age 16. Reports are uploaded to an Access database. Only results from venous blood lead tests are entered into the database. Results based on urine, hair, and capillary lead tests are excluded.

Each report is assigned a personal identification number so that individuals with more than one test can be identified. The database has an automated matching algorithm to assign ID numbers, and new reports each week with elevated blood lead levels (EBLLs) are reviewed manually to ensure that ID numbers are accurate.

The database is updated with additional information obtained during follow-up of individuals with EBLLs (see below). The database includes identifiers, demographics, information about source of exposure to lead, and name/address of employer for work-related exposures.

Each record entered into the database has a quality control visual check on a monthly basis for any data entry errors, duplicate entries, missing data, and illogical data.

Follow-up with individuals with elevated blood lead levels

The ABLES protocol for case follow-up going back to 1997 is as follows: Interviews are conducted with reported individuals who had a blood lead level (BLL) of 25 micrograms per deciliter (µg/dL) or greater, or with BLLs ranging from 10 to 24 µg/dL if the source of their lead exposure has not been identified from the laboratory report or a previous report or interview. A letter is sent explaining Michigan's lead surveillance program and inviting the person to answer a 15-20 minute telephone questionnaire. The questionnaire collects patient demographic and address information, work exposure and history information, symptoms related to lead exposure, and information on potential non-work lead-related exposures. The interviewee is asked an open-ended question about why they were tested for lead and what they believe their source of lead was. Non-work lead exposure questions address activities related to: home renovations; hobbies, such as making lead bullets and fishing sinkers, pottery with glazes, and stained glass; firearm target practice; use of imported ceramics; use of imported spices; use of selected imported cosmetics; and retained bullet fragments from a gunshot wound. The questionnaire also collects information about children under age 6 living in the home. Trained interviewers administer the questionnaire.

Starting April 2016, all Flint residents age 18 and older reported with an EBLL, defined as a BLL of 5 µg/dL or greater and living in one of the seven zip codes the State had identified as being on the Flint Water System, have been contacted for an interview. (Follow-up with EBLL Flint residents ages 16 and 17 has been conducted by the Greater Flint Health Coalition, which does in-home nursing case management for all children with EBLLs.) In addition to the standard ABLES questionnaire, the Flint resident EBLL interview questionnaire includes a one-page supplement asking about exposure to drinking water and use of water filters following the water change in April 2014.

Following completion of data collection, MSU assigns an exposure source code to all individuals where exposure information is provided by the laboratory or provider or ascertained from the interview. Exposure codes include: work, hobby (e.g., firearms, stained glass making), pica, remodeling, other non-work. Where no known exposure source was identified in the interview or doctor report, exposure source was coded "none identified." Among those coded "none identified," an additional code of "water?" was assigned if the individual indicated drinking water in the open-ended exposure questionnaire about the reason for testing/source of exposure or the doctor responded to a faxed request that the exposure to lead was from drinking water.

MSU refers those individuals designated "water?" to MDHHS CLPPP with a recommendation that the individuals' homes be tested for lead in their drinking water, and, if children under the age of six are living in the home, also testing for lead in paint, soil, and other media.

MDHHS CLPPP forwards these referrals to an environmental testing company under contract with the MDHHS Lead Safe Home Program (LSHP) to conduct environmental

assessments of lead in homes in Flint. The company reports back to MDHHS CLPPP the results of their efforts to contact the individuals and conduct the environmental assessments. The report of completed environmental assessments, including water sampling results, are provided to MDHHS LSHP, which enters the testing results by address into a database it uses to track environmental lead assessments statewide.

Analytical files

Four tables from the MSU ABLES Access database were provided to MDHHS CLPPP for all blood lead reports of individuals age 18 and older tested from January 1, 2010 through October 31, 2017 where Flint Michigan was listed as the address. These included a table of blood lead test reports, a table with demographic information, an address table, and a table of interviewed individuals – all linked by the assigned ID number.

An analytical file was prepared in Excel that included, for each blood lead test report, the blood lead test result, date of the test, ID and name of the tested individual, zip code, birthdate, age at the time of the test, race, gender, and exposure code. Reports of BLLs greater or equal to 5 µg/dL were identified as elevated (EBLL). Records were then selected for those addresses with zip codes 48501-48507 because addresses in these seven zip codes very closely align with the water distribution system of the FWS, and are used by MDHHS when analyzing BL data on children in Flint.[8]

Data were summarized for all reports, and, because some individuals were tested more than once, by individuals after deduplication and only including the highest blood lead level. The analysis was done using three timeframes. The first timeframe was by year from 2010 through 2017. Deduplication was within each year; thus, an individual would be counted once in each year tested. The second time frame encompassed three periods: before, during, and after the water change (1/1/2010-4/24/2014, 4/25/2014-10/15/2015, and 10/16/2015-10/31/2017). Deduplication was within each period; thus, an individual would be counted once in each period. The third time frame included all individuals tested from April 25, 2014 through October 31, 2017, counted once.

A second analytical file was prepared by linking IDs of individuals with EBLLs tested 4/25/2014 or after to the MSU interview table, to include interview data on home water usage for drinking and cooking and presence of water filters.

A third analytical file was prepared linking the addresses of EBLL individuals tested 4/25/2014 or after with water testing data from five sources: (1) the address file of completed environmental assessments maintained by MDHHS LSHP; (2) a publicly available database of results of water testing in 2016 and 2017 in Flint posted at www.michigan.gov/flintwater; (3) water test results provided by the Michigan Department of Environmental Quality (DEQ) that were collected by the FWS in 2014 and 2015 as part of mandated water quality monitoring for all community water supplies; (4) results provided by Virginia Polytechnic Institute and State University (“Virginia Tech”) (http://flintwaterstudy.org/about-page/about-us) of water testing results in 2015 and 2016; and (5) water test results collected by the US Environmental Protection

Agency (EPA) in 2016. Information was extracted from all sources indicating whether any water sample from that address was at or above the EPA action level of 15 parts per billion (ppb). The LSHP database indicated whether lead was detected in other media (dust, soil, and paint) and whether any of the sample results were above federal or state standards.

Data analysis

A timeline was constructed of BL test dates as associated with major water-related events including changes in water source and publicity/public health advisories about lead in the water. Descriptive statistics summarized the BL testing data by time period, demographics, and lead exposure sources. Descriptive statistics also summarized environmental testing results in homes for lead in water, dust, soil, and paint. Data from interviews of EBL individuals were used to summarize self-reported consumption of water.

RESULTS

Tests

There were 20,018 BL tests on 17,169 individuals age 18 and older with a Flint address in one of the seven zip codes, from January 2010 through October 2017; 327 (1.9%) of these individuals had at least one elevated test result.

Figure 1a displays the number of tests each quarter for January 2010 through December 2014 and Figure 1b displays the numbers of tests for each quarter for Jan 2015 through October 2017. The number of tests remained relatively constant, with an average of 50 tests per quarter through 2014. In the fourth quarter of 2015, the number of tests began to increase, in association with the beginning of publicity about the link between the drinking water and lead exposure. In January 2016, after MDHHS recommended that all individuals in Flint be tested for lead, adult blood lead testing rose dramatically; 9,679 adults were tested in the first quarter of 2016, compared to 34 in the first quarter of 2015. Subsequent testing frequency declined, but even in the third quarter of 2017 there were 691 tests, which was much greater than the number of tests in any quarter prior to public awareness of lead in the water. (Note: Data for the fourth quarter 2017 are incomplete because they are only for the first month, October.)

Figure 1 a: Number of Blood Lead Tests by Quarter, 2010 - 2014, Flint, MI residents ages 18 and older.

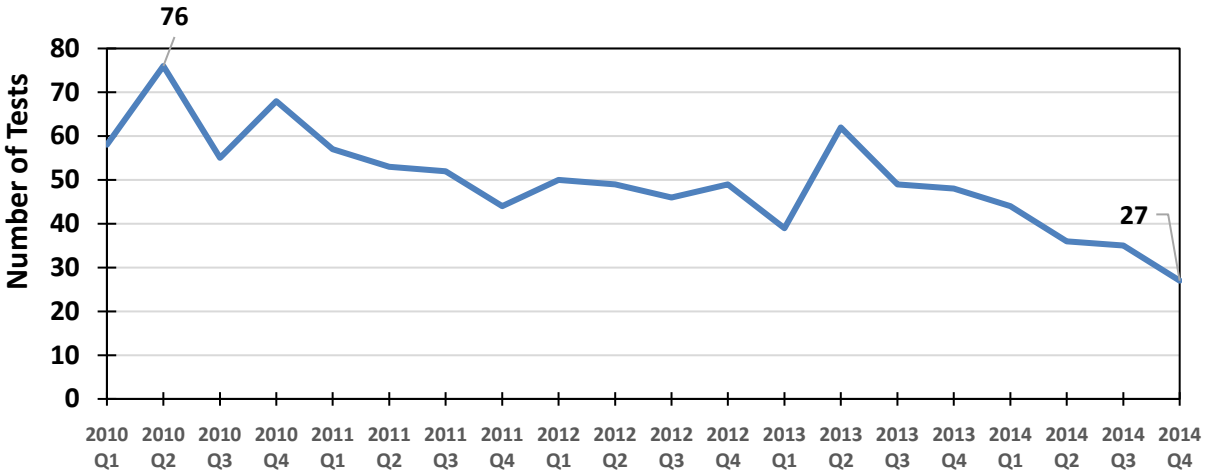

Figure 1 b: Number of Blood Lead Tests by Quarter, 2015 - 2017, Flint, MI residents ages 18 and older

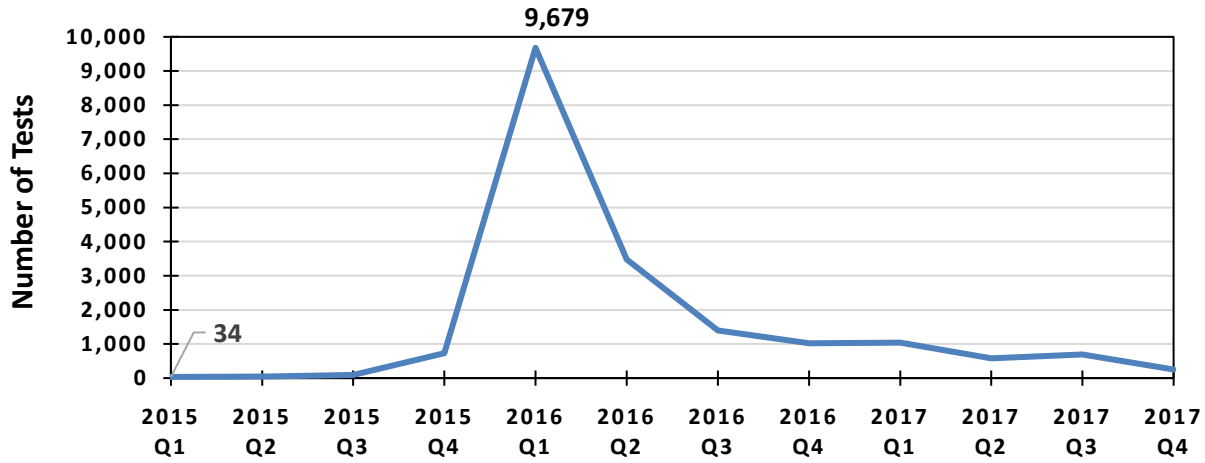

Table 1 displays the number of tests, number of individuals tested each year, and the number and percent of individuals with EBLLs, for 2010 through October 2017. Individuals were counted once in each year for which they had a test report, and their highest BLL was used for counts of individuals with EBLLs. The number of Flint adults tested for lead increased from an average of 178 per year between 2010 and 2014 to 869 in 2015 and 14,299 in 2016. The number of individuals with EBLLs ranged from 20 to 33 each year until 2016, when there were over 200 EBLL individuals. The percent of

tested individuals with EBLLs ranged from 10.1% to 18.1% for the years before the Flint water emergency, and then declined to less than 2% for 2016 and 2017.

Table 1: Number of Blood Lead Test Reports, and Individuals (number and percent) with BLL ≥ 5 µg/dL, Flint, MI residents ages 18 and older, 2010-2017

Year	Blood Lead Test Reports	Individuals	BLL ≥ 5 µg/dL	
			#	%
2010	257	227	23	10.1
2011	206	178	28	15.7
2012	194	181	22	12.2
2013	198	171	31	18.1
2014	142	131	20	15.3
2015	897	869	33	3.8
2016	15,570	14,299	219	1.5
2017*	2,554	2,268	43	1.9

* Partial year count through October only.

Demographics

Demographic characteristics of tested individuals and their association with EBLL status, for the three time periods – before (Period 1), during (Period 2), and after (Period 3) the change in water source – are shown in Table 2.

Gender: Forty-seven percent of those tested in Period 1 were female. However, by Period 3, when testing increased dramatically, more than two times more women were tested than men. Males exceeded females in the number and percent of EBLLs in all three periods, although by Period 3, the percent with EBLLs declined in both men and women.

Age group: The percent of those tested that had an EBLL was lower in all age groups in the third period, compared to the first. This decline was most pronounced in 25-44 year olds.

Race: Data are very incomplete for race, with only 42.4% where race was determined in Period 1, 41.9% in Period 2, and 29.7% in Period 3. Among those with race determined, Whites were more likely than Blacks to have an EBLL in the first two time periods, while in the third time period, Blacks were more likely to have an EBLL. No conclusions should be drawn as to the representativeness of these findings because of incomplete data.

Table 2: Gender, age, and race of tested individuals for three time periods, by EBLL status (number and percent), Flint, MI residents ages 18 and older.*

Demographics	Period 1: 1/1/2010-4/24/2014			Period 2: 4/25/2014-10/15/2015			Period 3: 10/16/2015-10/31/2017		
	Total	# EBL	% EBL	Total	#EBL	%EBL	Total	#EBL	%EBL
Gender									
Female	310	9	2.9	259	8	3.1	11,077	91	0.8
Male	357	60	16.8	183	24	13.1	5,249	162	3.1
Total	667	69	10.3	442	32	7.2	16,326	253	1.5
Age group									
18-24	98	5	5.1	33	0	0.0	1,951	13	0.7
25-34	88	12	13.6	35	2	5.7	2,388	11	0.5
35-44	141	19	13.5	82	10	12.2	1,994	28	1.4
45-54	144	17	11.8	102	10	9.8	2,752	54	2.0
55-64	87	7	8.0	96	5	5.2	3,504	71	2.0
65-74	71	7	9.9	57	1	1.8	2,292	47	2.1
75+	38	2	5.3	37	4	10.8	1,462	30	2.1
Total	667	69	10.3	442	32	7.2	16,343	254	1.6
Race									
White	174	27	15.5	140	14	10.0	2,135	37	1.7
Black	108	13	12.0	45	0	0.0	2,691	89	3.3
Other	1	0	0.0	0			35	3	8.6
Total	283	40	14.1	185	14	7.6	4,861	129	2.7

* Counts in each category are only for those about whom gender, age or race information are available.

Sources of exposure

Based on information from interviews, providers, and laboratories, sufficient information was available to assess likely sources of exposure and assign an exposure code (including "none identified") for 45 (65.2%) EBLL individuals in Period 1, 16 (50.0%) EBLL individuals in Period 2, and 108 (42.5%) EBLL individuals in Period 3. The proportion of EBLL individuals for whom exposure source was assigned varied by blood lead level group (5-9, 10-24, and $\geq$ 25 µg/dL) for each time period. Source of exposure was assigned for 32.5% to 37.1% in the 5-9 µg/dL group across the three time periods. Source of exposure was assigned to a much greater degree across all three time periods for the two higher blood lead level groups. (Table 3) This is most likely because of the ABLES protocol for interviews based on blood lead level, as described in the methods section above.

Table 3: Number and percent of EBLL Individuals with exposure assigned, by blood lead level groups in each time period, Flint, MI residents ages 18 and older.

Period 1 (January 1, 2010-April 24, 2014)

Exposure	**5 - 9 µg/dL**		**10-24 µg/dL**		**≥25 µg/dL**		**Total**	
assigned	#	%	#	%	#	%	#	%
Yes	13	37.1	22	91.7	10	100.0	45	65.2
No	22	62.9	2	8.3	0	0.0	24	34.8
Total	35	100.0	24	100.0	10	100.0	69	100.0

Period 2 (April 25, 2014-October 15, 2015)

Exposure	**5 - 9 µg/dL**		**10-24 µg/dL**		**≥25 µg/dL**		**Total**	
assigned	#	%	#	%	#	%	#	%
Yes	7	33.3	8	80.0	1	100.0	16	50.0
No	14	66.7	2	20.0	0	0.0	16	50.0
Total	21	100.0	10	100.0	1	100.0	32	100.0

Period 3 (October 16, 2015-October 31, 2017)

Exposure	**5 - 9 µg/dL**		**10-24 µg/dL**		**≥25 µg/dL**		**Total**	
assigned	#	%	#	%	#	%	#	%
Yes	68	32.5	32	84.2	5	71.4	108	42.5
No	141	67.5	6	15.8	2	28.6	146	57.4
Total	209	100.0	38	100.0	7	100.0	254	100.0

Table 4 illustrates the results of exposure assignment for each of the three periods. The number of individuals with work exposure in Period 3 was similar to the number in the two preceding periods, but the percent with work exposure was much less (73.3% and 93.8% compared to 19.4%). In Period 3, interview information from 57 individuals (52.7%) identified no known lead exposure source. Individuals interviewed or their providers indicated that drinking water was the reason for the test and/or the source of exposure for 54 (94.7%) of the 57 with "unknown" exposure source.

Table 4: Sources of lead exposure among EBLL individuals for three time periods: Number and percent of those for whom exposure source was assigned, Flint, MI residents ages 18 and older.

Assigned exposure source	**Period 1: 1/1/2010-4/24/2014**		**Period 2: 4/25/2014-10/15/2015**		**Period 3: 10/16/2015-10/31/2-17**	
	#	**%**	**#**	**%**	**#**	**%**
Work	33	73.3	15	93.8	21	19.4
Retained bullet	10	22.2	0	0.0	26	24.1
Other	2	4.4	0	0.0	4	3.7
None identified	0	0.0	1	6.3	57	52.7
Total Assigned	45	100.0	16	100.0	108	100.0

Water usage reported by EBLL individuals

Eighty-eight adults with EBLLs who were interviewed between April 2016 and October 2017 provided answers to questions about water testing and use of water in their homes since April 2014 (Table 5). Less than half (42.1%) reported that their water had been tested. Over 80% drank and cooked with water from the faucet. Sixteen (18.2%) reported not using water filters for water from their faucets, of which only two reported not drinking water from the faucet or using it for cooking.

Table 5: Number and percent of 88 EBLL individuals interviewed April 2016-October 2017 reporting water testing and usage, Flint, MI residents age 18 and older.

Drinking Water Responses	Was your water tested for lead?		Did you drink from the faucet?		Did you cook with water from the faucet?		Did you use water filters where you obtained drinking/cooking water?	
	#	%	#	%	#	%	#	%
Yes	37	42.1	71	80.7	74	84.1	66	75.0
No	32	36.3	13	14.8	9	10.2	16	18.2
DK/NA*	19	21.6	4	4.5	5	5.7	6	6.8
Total	88	100.0	88	100.0	88	100.0	88	100.0

* Don't know or not answered

Water testing at homes of EBLL individuals

There were 298 valid street addresses that matched with 262 individuals tested with EBLLs any time between 4/25/2014, when the water source changed to FWS, until 10/31/2017. (Thirty-six (13.7%) of these 262 individuals had more than one street address in Flint in this time period.)

Water test results were available on 61 (20.5%) of the matched street addresses; 13 had at least one result greater than or equal to the EPA action level of 15 ppb lead, which was 4.4% of all 298 street addresses and 21.3% of the addresses with available test results. (Table 6) Sixteen (26.2%) of these street addresses with water test results were residences of EBLL adults with exposure assigned “water?”, of which six (37.5%) had at least one result at or above the EPA action level.

Only two street addresses with water results matched with EBLL individuals tested in Period 2. Water testing for both addresses occurred after the water source returned to the DWSD in October 2015, and neither one exceeded the EPA action level.

Table 6: Water testing results for street addresses of EBLL Individuals tested 4/25/2014-10/31/2017 (Period 2 and Period 3 combined – individuals counted once)

Water results	#	%
<15 ppb	48	16.1
=>15 ppb	13	4.4
No results in any of the databases	237	79.5
Total	298	100.0

Lead dust, soil, paint testing at homes of EBLL individuals

Environmental testing for lead in dust, soil, and paint was conducted at fifteen street addresses of EBLL individuals in 2016 and 2017. No lead was detected in any of these media at seven (46.7%) of the homes. Four (26.7%) were found to have lead levels in dust and six (40%) to have of lead levels in paint above federal or state standards. (Table 7). Six total had results in at least one media.

Two of the fifteen homes had a water sample ≥15 ppb. One of these had lead paint hazards and one did not have lead detected in any of the three other media. (Data not shown in Table 7.)

Table 7: Results of environmental investigations at 15 homes of EBLL individuals, Flint, Michigan residents age 18 and older tested 4/25/2014-10/31/2017.

	Sample Type:					
Other lead test results	**Dust**		**Soil**		**Paint**	
	#	%	#	%	#	%
Not detected	7	46.7	7	46.7	9	60.0
Present, below federal/state standards	4	26.7	8	53.3	0	0.0
Present, above federal/state standards	4	26.7	0	0.0	6	40.0
Total	15	100.0	15	100.0	15	100.0

Discussion

Public health surveillance for adult lead exposure based on laboratory reporting of blood lead test results has been ongoing since 1998 in Michigan. Historically, its focus has been on lead exposure at work. This is because legal standards for worker protection from lead hazards require blood lead testing of lead-exposed workers exposed above the air action level of 25 micrograms per cubic meter ($\mu g/m^3$). Data from blood lead testing of adults in Flint prior to the Flint water emergency were similar to data elsewhere in Michigan and nationwide in that testing identified that the source for lead in adults with EBLLs was typically from occupational exposure.[9] About 80% of adults with EBLL were tested because of occupational lead exposure until the marked increase in adult testing in Flint in early 2016. The increase in testing was in response to concern about lead in the drinking water and recommendations from officials that everyone in Flint be tested.

On average, in the five years preceding awareness of lead in the drinking water, there were 178 individuals tested annually. By contrast, 16,343 individuals were tested between September 2015 and September 2017 (Period 3) following the recognition of lead in the drinking water, which constituted 22.3% of the 73,157 people age 18 and over living in Flint based on the 2012-2016 estimates from the U.S. Census.[10] The individuals tested in Flint in Period 3 may not have been representative of the adult population as a whole. A greater proportion of tested Flint adults were age 65 or older (22%) than that of the general population (approximately 16%) and were female (67.8% compared to 52.7%).The percent White and Black were very similar to that in the general population (43.9% and 55.4% compared to 43.6% and 57.2%); however, it is important to note that race information was available on only 29% of the tested individuals in Period 3, and there are no data to determine if this small group is or is not representative of the entire population of Flint.

The large increase in testing occurred after the drinking water source was returned to the DWSD from the FWS, in October of 2015. Because lead in blood in adults has a half-life of only 28 to 36 days,[11] blood lead results measured months after lead levels in water began to decrease would likely underestimate the prevalence of elevated blood lead levels in adults during the FWS period, if the lead in the water was contributing to blood lead levels. It should be noted that boil water advisories in early 2015 may have resulted in subsequent water avoidance behaviors well before official recognition in September 2015 of the elevated lead levels in the water. A study of trends in blood lead levels in children in Flint found that they decreased about 50% from their initial rise after the switch to FWS water following boil water advisories in early 2015, and that they returned to pre-2014 levels after the change back to water from the DWSD.[12]

Between 10% and 18% of adults tested annually from 2010-2014 had elevated blood lead levels of greater or equal to 5 µg/dL. In Period 3 (October 16, 2015- October 31, 2017) the prevalence of EBLL in the 16,343 tested individuals was 1.6%. The estimated prevalence of EBLL in adults age 20 and older in the United States from the 2013-2014 National Health Nutrition Examination Survey (NHANES)[13] was also 1.6%.[14] The NHANES is based on a representative sample of the U.S. population designed to assess the health and nutritional status of adults and children in the United States. It

does not collect information from individuals tested for lead on sources of lead exposure, such as exposure at work or from lead-related hobbies.

Information from providers and laboratories and interviews of EBLL individuals provided information to assess possible exposure for 108 (42.5%) of the 254 EBLL individuals in Period 3. The number of individuals with work exposure in Period 3 was similar to the numbers in the preceding two periods (21 compared to 33 and 15) but, because of increased testing, the percent with work exposure was only 19.4% compared to 73.3% and 93.8% in periods 1 and 2, respectively.

Retained bullet fragments are known to contribute to elevated blood lead levels in adults.[15] They were the likely source of the lead exposure for 26 EBLL individuals in Period 3 (24.1% of the 108 with exposure source assigned and 23 (26.1% of the 88 interviewed individuals). It should be noted that an additional six EBLL individuals who were assigned other lead exposure sources also reported a history of bullet wounds, but indicated they did not have retained bullet fragments. Thus, 29 of the 88 interviewed EBLL adults (33.0%) had gunshot wounds.

The prevalence of gunshot wounds in this population was considerably higher than in that reported in published studies. In 2017, the Pew Foundation found that 3% of adults in nationwide survey had ever had a gunshot injury.[16] In a cross-sectional study of jail detainees in Washington DC, 24% reported a history of gunshot wounds,[17] and 14.5% of inmates surveyed in 5 jails reported a history of having been shot.[18] Only two of the 26 EBL adults in Flint with retained bullets had been tested prior to community-wide screening that started in 2016. We have no data to indicate whether the 24 with retained bullets first tested in 2016 and 2017 elected to be screened because of concerns about prior gunshot injury or whether they elected to be screened because of the public health screening recommendation based on concerns about water.

In Period 3, no known source of lead exposure was identified among 57 (52.7%) of the 108 EBLL adults with exposure information ascertained from an interview or provider report. Fifty-four (94.7%) of the 57 attributed Flint drinking water as the reason for the blood lead test or the reason for the EBLL. There is no data to confirm the sources of any of the reported lead exposure, and there could have been other exposure sources to which the individuals or their providers were unaware.

Lead in drinking water is known to contribute to the prevalence of EBLLs in children.[19,20,21,22,23] Because of confounders, especially lead in paint in older houses, it is difficult to quantify the contribution of lead in water to blood lead levels in children, although estimates have ranged from 10% to 20%.[24,25] There is less evidence for the contribution of water to lead levels in adults; however two studies in Great Britain found an association between lead in tap water and blood lead levels.[26,27]

Eighty-eight interviewed individuals provided information on water usage in their home. Most used water from their faucets for drinking and cooking. Almost 20% reported not ever using water filters on their faucets in spite of widespread efforts to distribute water filters to the entire city of Flint. It is unknown if this finding is representative of the Flint population.

In an effort to link quantitative data from lead water testing that was undertaken after April 2014 with BL data, water testing results were obtained from five testing programs

and matched with street addresses of individuals tested after April 25, 2014 with EBLLs. In spite of large-scale efforts to collect water data throughout the city, only 61 (20.5%) of the 298 street addresses matched with water testing data. Thirteen of the 61 (21.3%) street addresses had at least one water test greater than or equal to the EPA action level of 15 ppb.

There are many caveats to the interpretation of the drinking water data. 1) A single water sample only represents the water quality at the moment the sample was collected. Most of the samples were collected in Period 3, after the water source had been switched back to the DWSD, and thus possibly after a majority of the scale containing lead had been removed from the water lines. 2) The water samples were collected for a variety of purposes and all may not have been collected in the manner prescribed by EPA's Lead and Copper Rule (LCR) testing, which is first-draw water taken after the water has been standing in the pipes for at least 6 hours.[28] 3) It is unknown whether the 15 samples 15 ppb or higher were taken from water sources used for drinking. 4) There were likely multiple sources of lead in the water, including particulate lead from damage to the water infrastructure and soluble lead from various water lines, plumbing, and faucets. Particulate lead in water samples could cause water lead levels to vary widely. Because of all the above factors, individuals could have been exposed to elevated lead in water but not identified as such based on water testing. In addition, it should be noted that drinking water sampling as part of the EPA's LCR is not designed to determine people's exposure to lead, but is used as a measure of corrosion control for the water system. Other limitations to the interpretation of drinking water data and its association to blood lead levels are described elsewhere. [29]

Because of small numbers and the many limitations in the drinking water data, no conclusions can be drawn about the association of past water testing data and data on individuals with EBLLs. Lead exposure from drinking water in Flint should be markedly reduced by 2020, when replacement of all lead service lines is expected to be completed. Water filter use is encouraged while pipe replacement is underway.[30]

Until 2016, the ABLES program nationwide and in Michigan defined an elevated blood lead level in adults as a BLL ≥ 10 µg/dL. Although the BLL for adults defined as elevated was reduced to ≥ 5 µg/dL nationally in 2016,[31] on the basis of mounting evidence for adverse health outcomes among adults with these lower levels,[32] the Michigan ABLES program has only been able to collect exposure information from follow-up interviews with adults with BLLs of ≥10 µg/dL because of limited resources, with the exception of interviews of EBLL adults in Flint starting in April 2016. Unfortunately, resources were not available to interview Flint EBLL adults tested before April 2016, when the majority of testing occurred; thus, information on exposure was not available for 50% of the EBLL adults tested during the FWS period and over 58% of EBLL adults tested after the change of the water back to the DWSD.

Recommendations

Efforts should continue to encourage water filter use until lead service line replacement is completed and lead-containing faucets or plumbing are replaced.

Additional investigation is needed to understand the magnitude of and risk factors for firearm injuries in Flint, so that preventive actions can be taken.

Resources should be identified to support follow-up interviews with all EBLL adults in Flint, tested since April 2014.

Resources should be identified to support follow-up interviews with all Michigan adults with BLLs of 5 µg/dL or higher. This would provide comparison data to the data from Flint, and would provide population-based data to target interventions to adults in communities throughout Michigan that are at risk of exposure to lead.

References

[1] CDC-NIOSH. Elevated Blood Lead Levels Among Employed Adults — United States, 1994–2013. Morb Mortal Wkly Rept, October 14, 2016 / 63(55):59-65.
[2] Lead exposure in general industry: http://www.michigan.gov/documents/CIS_WSH_part310_35615_7.pdf
[3] Lead exposure in construction: https://www.michigan.gov/documents/CIS_WSH_part603_35656_7.pdf
[4] See summary data reports at www.michigan.gov/flintwater.
[5] MLive Michigan. Elevated lead found in more Flint kids after water switch, study finds. http://www.mlive.com/news/flint/index.ssf/2015/09/study_shows_twice_as_many_flin.html#incart_river_home
[6] Hanna-Attisha M, LaChance J, Sadler RC, Champney Schnepp A. Elevated blood lead levels in children associated with the Flint drinking water crisis: a spatial analysis of risk and public health response. Am J Public Health 2016;106:283–90. http://dx.doi.org/10.2105/AJPH.2015.303003
[7] Kennedy C. et al. Blood lead levels among children aged <6 years – Flint Michigan 2013-2016. MMWR Morb Mortal Wkly Rep. 2016 Jul 1;65(25):650-4. doi: 10.15585/mmwr.mm6525e1
[8] www.michigan.gov/flintwater
[9] Centers for Disease Control and Prevention. Adult blood lead epidemiology and surveillance--United States, 2008-2009. MMWR Morb Mortal Wkly Rep. 2011 Jul 1;60(25):841-5.
[10] U.S. Census. American FactFinder. Available at thttps://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=CF
[11] ATSDR. Case Studies in Environmental Medicine (CSEM) Lead Toxicity. Available at . https://www.atsdr.cdc.gov/csem/lead/docs/lead.pdf.
[12] Zahran, S, MdElmurry SP, Sadler RC. Four phases of the Flint Water Crisis: Evidence from blood lead levels in Children. Environmental Research 157 (2017) 160-172.
[13] https://www.cdc.gov/nchs/nhanes/index.htm
[14] Adrienne Ettinger. Centers for Disease Control and Prevention. Personal communication 1/18/2018
[15] McQuirter JL et al. Changes in blood lead concentration up to 1 year after a gunshot wound with a retained bullet. Am J Epidemiol 2004; 15:683-692.
[16] Pew Research Center. “America’s Complex Relationship with Guns”. June 2017. p. 42. Available at https://www.pewsocialtrends.org/2017/06/22/guns-and-daily-life-identity-experiences-activities-and-involvement/
[17] May JP, Hemenway D, Pitts KR. Medical care solicitation by criminals with gunshot wound injuries: A survey of Washington DC jail detainees. J Trauma. 2000; 48:130-132.
[18] May JP, Hemenway D, Hall A. Do criminals go to the hospital when they are shot? Injury Prevention 2002; 8:236-238.
[19] Brown MJ et al. .Association between children’s blood lead levels, lead service lines, and water disinfection, Washington, DC, 1998–2006. Environmental Research. 2011; 111: 67–74
[20] President’s Task Force on Environmental Health Risks and Safety Risks to Children. Key Federal Programs to Reduce Childhood Lead Exposures and Eliminate Associated Health Impacts. Nov 2016. Available at https://ptfceh.niehs.nih.gov/features/assets/files/key_federal_programs_to_reduce_childhood_lead_exposures_and_eliminate_associated_health_impactspresidents_508.pdf.
[21] Centers for Disease Control and Prevention. Low level lead exposure harms children: A renewed call for primary prevention. Report of the Advisory Committee on Childhood Lead Poisoning Prevention, January 2012. Available from: http://www.cdc.gov/nceh/lead/acclpp/final_document_030712.pdf
[22] Brown MJ, Margolis S. Lead in drinking water and human blood lead levels in the United States. Morb Mortality weekly Review August 10, 2012, Supplement/Vol. 61.
[23] Sanders AE, Slade GD. Blood lead levels and dental caries in U.S. children who do not drink tap water. Am J Prev Med 2018;54(2):157-163.
[24] Zartarian V, Xue J, Tornero-Velez R, Brown J. Children's Lead Exposure: A Multimedia Modeling Analysis to Guide Public Health Decision-Making.Environ Health Perspect. 2017; 125(9):097009. doi: 10.1289/EHP1605

[25] Lanphear BP, Hornung R, Ho M, Howard CR, Eberly S, Knauf K. Environmental lead exposure during early childhood [published correction appears in *JPediatr*. 2002;140(4):490]. J Pediatr. 2002;140(1):40–47.
[26] Pocock SJ, Shaper AG, Walker M, Wale CJ, Clayton B. Effects of tap water lead, water hardness, alcohol, and cigarettes on blood lead concentrations. Epidemiol Comm Health 1983;37:1–7.
[27] Watt GCM, Britton A, Gilmour WH, et al. Is lead in tap water still a public health problem? an observational study in Glasgow. BMJ 1996;313:979–81.
[28] U.S. Environmental Protection Agency. Lead and Copper Rule Quick Guide. Available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=60001N8P.txt
[29] Triantafyllidou S, Edwards M. Lead (Pb)in tap water and in blood: implications for lead exposure in the United
States. Crit Rev Environ Sci Technol. 2012;42(13):1297–1352
[30] http://www.michigan.gov/flintwater
[31] CDC. National Notifiable Diseases Surveillance System. Lead, elevated blood levels. 2016 Case definition; 2015. Atlanta, GA: US Department of Health and Human Services, CDC;
2015. https://wwwn.cdc.gov/nndss/conditions/lead-elevated-blood-levels/case-definition/2016/
[32] Association of Occupational and Environmental Clinics. Medical management guidelines for lead-exposed adults. Washington, DC: Association of Occupational and Environmental Clinics;
2013. http://www.aoec.org/documents/positions/mmg_revision_with_cste_2013.pdf