

In the article, “National Survey of Lead Service Line Occurrence,” by David A. Cornwell, Richard A. Brown, and Steve H. Via, in the April 2016 issue of *Journal AWWA* (Vol. 108 No. 4), there were errors in specific rows of Table 3 that resulted from listing averages rather than totals. The corrected table is printed below. Additionally, the related discussion on page E185 should have stated the following: The national average of the 179 values was 37.2 LSLs/1,000 people for those CWSs that had LSLs.

TABLE 3 Number of LSLs per 1,000 population by regional group and population size

Regional Group	Number of Survey Responses ^a	LSLs Reported	Sum of Population Served by CWSs Reporting LSLs	LSLs/1,000 people ^a (N)
Population served <10,000				
Regions 1 and 2	5	116	26,943	4.3
Regions 3 and 4	7	607	20,619	29.4
Regions 5 and 7	25	10,352	101,003	102.5
Region 6	9	1,763	40,495	43.5
Regions 8, 9, 10	15	6,554	67,360	97.3
Population served 10,000–50,000				
Regions 1 and 2	9	29,301	210,994	138.9
Regions 3 and 4	15	15,690	309,698	50.7
Regions 5 and 7	25	69,378	669,812	103.6
Region 6	1 ^b	5,500	44,080	124.8
Regions 8, 9, 10	1 ^b	200	27,000	7.4
Population served >50,000				
Regions 1 and 2	14	74,687	10,886,214	6.9
Regions 3 and 4	15	156,596	5,969,296	26.2
Regions 5 and 7	26	790,039	9,190,396	86.0
Region 6	3	7,593	2,089,075	3.6
Regions 8, 9, 10	9	20,786	2,286,239	9.1
Total	179	1,189,162	31,939,224	37.2

LSL—lead service line, N—occurrence factor from the surveys regarding the average number of LSLs/1,000 people for water systems that have LSLs in a given population size and group

^aIncludes only utilities that have LSLs

^bTwo of the 15 groups have only one response each. Consequently, while the single response in each group had a population served that resulted in a narrow confidence interval, caution should still be used in interpreting the results.

National Survey of Lead Service Line Occurrence

DAVID A. CORNWELL,¹ RICHARD A. BROWN,¹ AND STEVE H. VIA²

¹Environmental Engineering and Technology Inc., Newport News, Va.

²AWWA, Washington, D.C.

This article summarizes findings from two AWWA-sponsored surveys of US community water systems (CWSs) that were conducted to gather information on lead-containing service lines (LSLs) in different regions of the United States for different sizes (population ranges) of water systems. The major objective of this research was to estimate the number of water systems with LSLs and the approximate number of LSLs nationwide and by region. These estimates were ultimately extrapolated to state occurrence. The survey results indicated a national estimate of 6.1 million LSLs

(either full or partial) currently present in CWSs of the United States, compared with 10.2 million estimated at the time of the original Lead and Copper Rule (LCR) (USEPA 1991); approximately 11,200 CWSs currently have LSLs compared with more than 15,000 estimated in the original LCR; 15 to 22 million people served by CWSs are estimated to have either a full or partial LSL serving their home out of a total population served by CWSs of about 293 million (7%); and approximately 30% of the CWSs surveyed (national average) reported having some LSLs in their system.

Keywords: LCR, lead, lead service line, LSL

Results from two AWWA-sponsored surveys regarding characteristics of drinking water service lines in US community water systems (CWSs) are described. For a detailed review of regulatory and water chemistry characteristics of lead in drinking water, see Brown and Cornwell (2015), Brown et al. (2015, 2013), Schock and Lytle (2011), and Schock (1989), and the many related references found within these papers.

PREVIOUS NATIONAL LEAD SERVICE LINE ESTIMATES

AWWA conducted a similar survey in 1988, summarized by the US Environmental Protection Agency (USEPA) (1991), Weston and EES (1990), and Frey (1989). The first two references present national lead service line (LSL) estimates. USEPA (1991) reported that the methodology in the initial AWWA survey estimated 7.0 million LSLs. These estimates were revised upward to 10.2 million by USEPA, as reported in the USEPA regulatory impact analysis (RIA) for the 1991 Lead and Copper Rule (LCR) (USEPA 1991). USEPA used the same database information and findings as the AWWA effort described in Weston and EES (1990) to revise the national estimate upward, though the methodology used by USEPA is not reported (USEPA 1991). The 10.2-million estimate for the number of LSLs in the United States by USEPA in the RIA was the most-referred-to value for the number of LSLs in the United States prior to the update estimate prepared through the work conducted in this article.

SURVEY METHODOLOGY AND PARTICIPATION

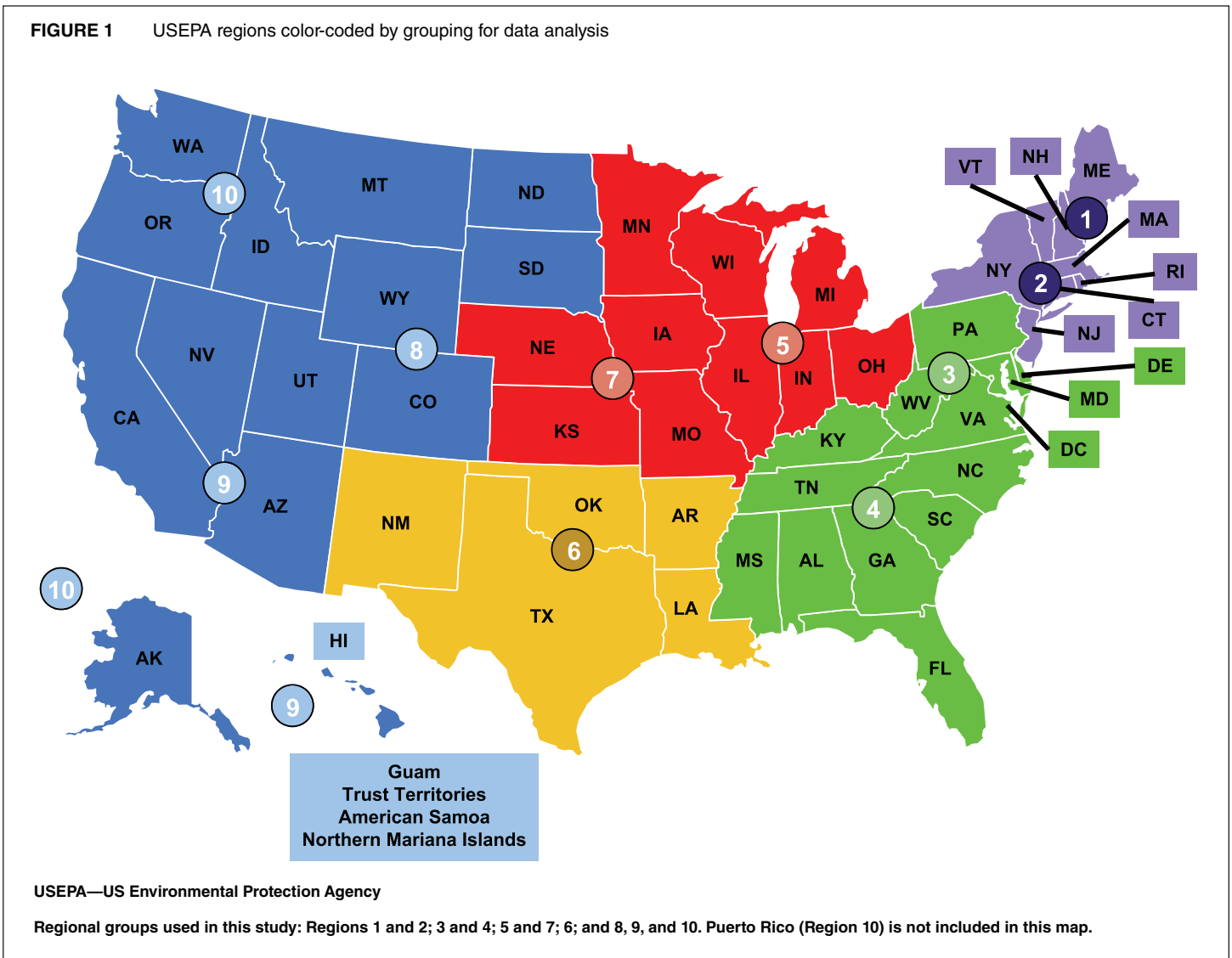
In order to prepare a national estimate of the number of LSLs, the information collected from two recent surveys was combined. The first survey is referred to as the 2011 survey in this article,

and the second survey is referred to as the 2013 survey. Preliminary information from the 2011 survey was presented in Dixon and Via (2011). Observations from the 2013 survey have not been published previously. The information presented in this article used the two surveys to estimate LSL occurrence.

2011 survey. The 2011 survey was conducted in the spring and summer of 2011. The survey targeted CWSs serving populations >500 people, not including US territories and American Indian lands. Water systems provided information through an online survey. All water systems meeting the target population with valid addresses in USEPA's Safe Drinking Water Information Systems (SDWIS) database were contacted via a postcard addressed to the listed water system contact. In addition, survey outreach included distributing a request for participation to all AWWA utility members in the United States. Direct contact with individual utilities (to recruit participating utilities) was complemented by an awareness-building effort with AWWA sections, the Association of Metropolitan Water Agencies, National Association of Water Companies, Water Research Foundation, National Rural Water Association, Association of State Drinking Water Administrators, and regulatory staff in individual states.

The survey included 12 questions developed to characterize the CWS and the components of the service lines associated with these systems, especially the lead-containing portions of the service lines. The questions specifically pertinent to the following discussion included an indication of whether the water system had LSLs and an estimate of how many LSLs are in the system (total, as well as the number of utility-owned LSLs and the number of customer-owned LSLs). The questions were clear that the response for the number of LSLs should include full and partial

FIGURE 1 USEPA regions color-coded by grouping for data analysis



LSLs and should include those owned by the utility or the homeowner. A full LSL is defined as a lead line extending from the water main to the house (i.e., customer and utility portions of the service line). A partial LSL is defined as having a lead line on either the customer or the utility side of the service line but not both (typically, lead on the customer side and some other material on the utility side). A location having either a full or partial LSL was classified as having an LSL and was treated the same in the analysis.

Responses were received from 774 CWSs in 49 states plus the District of Columbia (D.C.), including the following USEPA regional groupings (see Figure 1 for a map of USEPA regions): 57 combined in USEPA Regions 1 and 2 (7% of the total responses received); 203 in Regions 3 and 4 (26%); 222 in Regions 5 and 7 (29%); 122 in Region 6 (16%); and 170 in Regions 8, 9, and 10 (22%).

2013 survey. The 2013 survey was conducted during the summer of 2013. This survey effort included both an online survey and a shorter telephone-interview survey. The online survey was

provided to all US AWWA water utility members. In-person telephone interviews targeted CWSs serving populations >250,000. As in the 2011 survey, the key questions were whether LSLs were present and, if so, how many. The questions were clear that the response for number of LSLs should include full and partial lines and should include those owned by the utility or homeowner as discussed for the 2011 survey.

Responses were received from 204 CWSs in 43 states and D.C., including the following USEPA regional groupings: 21 combined in Regions 1 and 2 (10% of responses received); 35 in Regions 3 and 4 (17%); 37 in Regions 5 and 7 (18%); 14 in Region 6 (7%); and 97 in Regions 8, 9, and 10 (48%).

Combined responses of the two surveys. The following subsections characterize the responses received from the combined surveys, including handling of duplicate responses; conflicts between responses; and a summary of responses by population, water source, and USEPA region.

Duplicate responses. There were 39 CWSs that responded more than once (35 responded once to each survey, and the others

TABLE 1 Percentage of CWSs reporting LSLs in their system by region and regional group

Regional Group	CWSs Reporting LSLs in Their Service Area			Systems With LSLs by Group (k) ^a		
	Yes	No	Not sure	Best	Max	Min
Population served <10,000						
Regions 1 and 2	8	23	6	26	38	22
Regions 3 and 4	16	95	21	14	28	12
Regions 5 and 7	43	78	32	36	49	28
Region 6	13	66	24	16	36	13
Regions 8, 9, 10	20	117	13	15	22	13
Population served 10,000–50,000						
Regions 1 and 2	12	9	2	57	61	52
Regions 3 and 4	18	28	8	39	48	33
Regions 5 and 7	37	29	9	56	61	49
Region 6	4	8	4	33	50	25
Regions 8, 9, 10	1	55	6	2	11	2
Population served >50,000						
Regions 1 and 2	16	2	0	89	89	89
Regions 3 and 4	17	26	9	40	50	33
Regions 5 and 7	27	4	0	87	87	87
Region 6	4	8	5	33	53	24
Regions 8, 9, 10	15	30	10	33	45	27
Total	251	578	149			
Average				30	41	26

CWS—community water system, k—occurrence factor from the surveys regarding percentage of water systems with LSLs for a given group and population size range, LSL—lead service line

^aBest—"not sure" ignored; Min—"not sure" = "no"; Max—"not sure" = "yes"

responded more than once to one of the surveys). These were converted to one response for each CWS using the following criteria, including how they answered the question (yes, no, or not sure) regarding whether they had LSLs:

- 14 systems reported “no” in multiple survey responses (no LSLs are present)
 - Used “no” for all 14 responses
- 12 systems responded “yes” in multiple survey responses (LSLs are present)
 - Used the response that reported the number of LSLs or used the most recent response if both reported the number of LSLs
- 4 systems reported “yes” in one survey and “no” in the other
 - Used the “yes” survey responses and the reported number of LSLs
- 9 systems reported “not sure” in one response and either “yes” or “no” in the other
 - Used the definitive (yes or no) response

Conflict between responses. There were instances in which water systems answered “no” or “not sure” to the question about whether their system had LSLs, but in another question they reported the number of LSLs in their system. The reported number of LSLs for these systems was used, and the response to the first question was changed to “yes” in each case (i.e., they apparently do have LSLs in their system).

Responses sorted by regional groups. Overall, the combined responses from both surveys included 978 CWSs in 49 of 50 states plus D.C. (no responses from New Hampshire). The responses were divided into the following USEPA regional groupings: 78 combined in Regions 1 and 2 (8% of responses received); 238 in Regions 3 and 4 (24%); 259 in Regions 5 and 7 (26%); 136 in Region 6 (14%); and 267 in Regions 8, 9, and 10 (27%). The rationale for the groupings are discussed in the “Data Analysis Considerations” section.

Source water. In the 2011 survey, there were 424 CWSs that used only groundwater (GW) and 350 that used at least one surface water (SW) source or groundwater under the direct influence of surface water or multiple GW and SW sources. In the 2013 survey, there were 69 that reported using GW and 135 that reported using SW. Overall, there were 485 (50% of responses) using GW and 493 (50%) using SW.

Population. There were 575 water systems (59% of responses) combined in both surveys serving populations <10,000, 230 (24%) serving populations between 10,000 and 50,000, and 173 (18%) serving populations >50,000. These three population ranges (sizes) were used in other sections of this study.

Calculations regarding the confidence interval associated with the survey results were completed and discussed in appropriate sections of this article. Confidence intervals were based on the population represented by the survey results for each region and

size rather than on the number of responses received. Population represented by the responses was used to determine the response-confidence interval for two reasons: first, calculations were performed by population; second, population directly relates to the number of service lines represented by survey responses. Therefore, statistical confidence was based on the number of service lines represented by the survey results compared with the total number of service lines in a specific grouping.

ESTIMATED NUMBER OF LSLs IN US WATER SYSTEMS

The documents developed during the 1991 LCR included an estimation of the number of LSLs in US water systems in order to establish the potential impact of the LCR requirements. In order to develop an updated estimate, combined data from the two surveys (2011 and 2013) and from the USEPA SDWIS database (USEPA 2015) were used to estimate the number of LSLs currently in water systems in each of the three population size ranges mentioned earlier.

Data analysis considerations. The combined results from the 2011 and 2013 surveys described here suggested that the distribution of data was different on the basis of population range, no matter whether the data were organized by state, region, or regional group.

As an example of LSL distribution by system size, in the combined total from Regions 1 and 2 the responses indicated that 26% of the utilities serving <10,000 population had LSLs; 57% of those serving 10,000 to 50,000 had LSLs; and 89% of those serving >50,000 population had LSLs. These distribution differences by population served can be seen in Table 1. Therefore, the three different population ranges were analyzed as separate groups.

If the responses were grouped by state (plus D.C.) and size, there would be 153 bins or groups (50 states plus D.C., three population ranges). However, using this approach resulted in many of the bins having no survey responses received, so a state approach was not possible. The next consideration was to group the data by the 10 USEPA regions such that there would be 30 bins or groups (10 regions, three sizes). However, in this grouping there were also several bins with no responses. The next step was to group the regions into logical combinations.

The selected grouping was done by combining regions that are likely to have similar LSL occurrence (Figure 1). The end result was five combined regions and three size ranges for 15 total bins or groups of data. The 99% confidence interval for the survey grouped in this manner was less than 1% for each of the 15 groups, based on the population served by survey responses versus the total population in each group.

Calculations. The survey data were used to develop two “occurrence factors” estimating the following: the percentage of water systems that have LSLs in each of the 15 groups, and the number of LSLs/1,000 population for utilities reporting LSLs in each of the same 15 groups. These factors were used in conjunction with information on the number of CWSs in the October 2013 USEPA SDWIS database (USEPA 2015) for these same 15 groups. The calculations used can be expressed as shown in Eqs 1 and 2 for each group (i.e., three population ranges and five regional groups, or 15 groups total).

$$M = k \times C \quad (1)$$

$$A = k \times N \times Pop \quad (2)$$

where M = estimated number of CWSs with LSLs calculated for a given group and population size range, k = occurrence factor from the surveys regarding percentage of water systems with LSLs for a given group and population size range, C = number of CWSs of a given population size for a given group in the SDWIS database, A = estimated number of LSLs for a given group in a given population size range, N = occurrence factor from the surveys regarding the average number of LSLs/1,000 people for water systems that have LSLs in a given population size and group, and Pop = combined population served by all the CWSs that make up C in the SDWIS database.

Table 2 lists the cumulative number of water systems and population for CWSs in each of the 15 groups defined earlier in the SDWIS database (USEPA 2015). The national estimate for LSLs uses values for k , N , and Pop , as defined here, for each of the 15 groups. C and k are used to estimate the number of CWSs reporting the presence of LSLs in their system. The C and Pop data are listed in Table 2, while k and N are based on survey results discussed in this article.

An alternative approach to Eq 2 would be to not use the k and N factors as written previously but instead divide the total number of reported LSLs within each of the 15 separate groups by the total population of all survey responses within these groups (total LSLs in survey from a group ÷ total population from all survey responses in a group whether they report having LSLs or not). This value multiplied by the total SDWIS population for the group would also give the total estimated LSLs within each group. Using this approach the results are similar to those reported in the “National Estimate of the Number of LSLs” section to follow (<4% difference).

Estimated number of LSLs/1,000 people (M). Of the 251 systems reporting the presence of LSLs in their systems, 72 did not report the number of LSLs. Consequently, only the 179 providing responses were used to calculate N , which is the number of LSLs/1,000 population served for only those utilities that have LSLs in their system. The value of N for these 179 water systems was calculated by dividing the reported number of LSLs by the population served by that utility, reported as LSLs/1,000 people. Then all the calculated values within each of the 15 groups were determined, as summarized in Table 3. The national average of the 179 values was 17.5 LSLs/1,000 people for those CWSs that had LSLs. Table 3 also shows the number of responses that reported having LSLs for each of the 15 groups or bins. These are shown for complete transparency, and it is important to note that two of the 15 bins have only one response each. Consequently, while the single response in each bin had a population served that resulted in a narrow confidence interval, caution should still be used in interpreting the results.

Estimation of the percentage of water systems with LSLs (k). There were 978 total responses combined for the two surveys, as follows:

- 251 responses indicating CWSs had LSLs
- 578 responses that CWSs had no LSLs
- 149 responses with incomplete or “not sure” responses

TABLE 2 SDWIS-reported population served by CWSs by regional group and system size

Regional Group	CWSs in Each Size Range (C)			Population Served by CWSs in Each Size Range (Pop)		
	<10,000	10,000–50,000	>50,000	<10,000	10,000–50,000	>50,000
Regions 1 and 2	5,030	457	105	4,865,530	10,799,643	26,675,234
Regions 3 and 4	11,666	971	283	14,590,382	20,926,632	49,466,710
Regions 5 and 7	10,258	770	163	12,861,672	16,314,613	26,151,359
Region 6	7,541	419	104	10,790,746	8,248,319	19,526,316
Regions 8, 9, 10	10,629	615	292	8,616,912	14,213,965	49,876,866
Total	45,124	3,232	947	51,725,242	70,503,172	171,696,485

Source: USEPA 2015

C—number of CWSs of a given population size for a given group in the SDWIS database, CWS—community water system, Pop—combined population served by all CWSs that make up C in the SDWIS database, SDWIS—Safe Drinking Water Information System

TABLE 3 Number of LSLs per 1,000 population by regional group and population size

Regional Group	Number of Survey Responses ^a	LSLs Reported	Sum of Population Served by CWSs Reporting LSLs	LSLs/1,000 people ^a (N)
Population served <10,000				
Regions 1 and 2	5	116	26,943	4.3
Regions 3 and 4	7	87	2,946	29.4
Regions 5 and 7	25	414	4,040	102.5
Region 6	9	1,763	40,495	43.5
Regions 8, 9, 10	15	437	4,491	97.3
Population served 10,000–50,000				
Regions 1 and 2	9	3,256	23,444	138.9
Regions 3 and 4	15	1,046	20,647	50.7
Regions 5 and 7	25	2,775	26,792	103.6
Region 6	1 ^b	5,500	44,080	124.8
Regions 8, 9, 10	1 ^b	200	27,000	7.4
Population served >50,000				
Regions 1 and 2	14	5,335	777,587	6.9
Regions 3 and 4	15	10,440	397,953	26.2
Regions 5 and 7	26	30,386	353,477	86.0
Region 6	3	7,593	2,089,075	3.6
Regions 8, 9, 10	9	2,310	254,027	9.1
Total	179	71,657	4,092,995	
Average				17.5

LSL—lead service line, N—occurrence factor from the surveys regarding the average number of LSLs/1,000 people for water systems that have LSLs in a given population size and group

^aIncludes only utilities that have LSLs

^bTwo of the 15 groups only have one response each. Consequently, while the single response in each group had a population served that resulted in a narrow confidence interval, caution should still be used in interpreting the results.

Table 1 summarizes the calculated k values (see Eq 1) as defined earlier. The “best estimate” of the k value was defined as the result of using only the “yes” and “no” columns. However, to estimate the range of potential results, the “Max” estimate for k counts the “not sure” with the “yes” responses and the “Min” counts “not sure” as a “no” response. This analysis allowed for a range of the k estimate to be determined.

The k value was calculated for each group of data by taking the total number of “yes” responses and dividing by the number of

“yes” plus “no” responses (with “not sure” ignored, included with “yes,” or included with “no,” as described earlier). Table 1 shows calculated values for k when grouping the data by system size and regional group (15 groups, five regional groups for three system sizes, as described earlier).

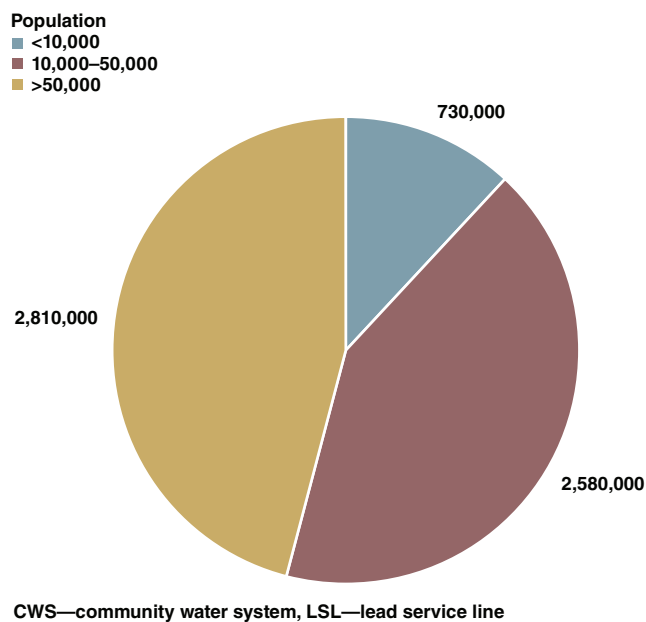
The survey confidence interval was calculated for the worst case in the k values of Table 1. This is the 10,000–50,000 population range for Region 6. There are 16 water systems with a combined population of >316,000, and the calculated k value is 50%

TABLE 4 Estimated number of LSLs nationally and by regional group

Regional Group	Population Served and Number of LSLs			Total
	<10,000	10,000–50,000	>50,000	
Regions 1 and 2	10,000	870,000	160,000	1,040,000
Regions 3 and 4	60,000	420,000	520,000	1,010,000
Regions 5 and 7	460,000	940,000	1,980,000	3,380,000
Region 6	80,000	340,000	20,000	440,000
Regions 8, 9, 10	120,000	10,000	130,000	250,000
Total	730,000	2,580,000	2,810,000	6,120,000

LSL—lead service line

FIGURE 2 National LSL estimate by population size range served by a CWS



(“Max” column in Table 1). The water systems in this region, in this population size range, include a population >8 million. At a 99% confidence level, the calculated confidence interval for the survey is <0.3%. Since this is so small, the results were not adjusted to account for a confidence interval around the survey results. Instead, the range was determined on the basis of the “not sure” (Min and Max) responses, as discussed earlier.

National estimate of the number of LSLs. The national estimate was calculated using Eq 2 and the surveys plus SDWIS data for the 15 groups, as described earlier. The values for *Pop* from Table 2, *N* from Table 3, and *k* from Table 1 were used for each of the 15 groups with results shown in Table 4. For example, for the combination of Regions 5 and 7 in the 10,000–50,000 systems size, the population was 16.3 million, the *N* value was 103.6 LSLs/1,000 people, and the *k* value was 0.56, resulting in an estimated 0.94 million LSLs ($16.3 \times 0.56 \times 103.6/1,000$). The

FIGURE 3 National LSL estimate by USEPA regional group

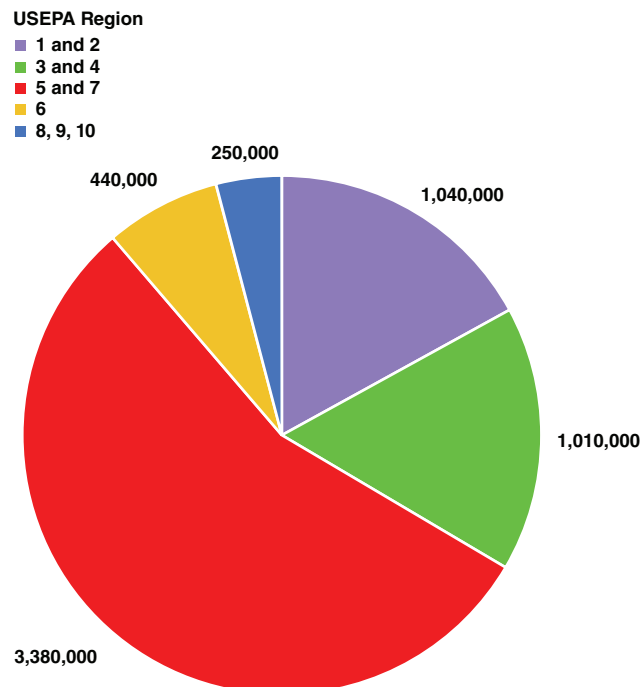
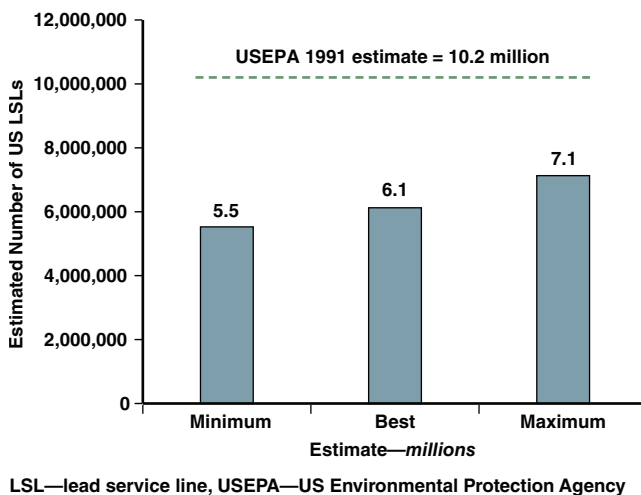
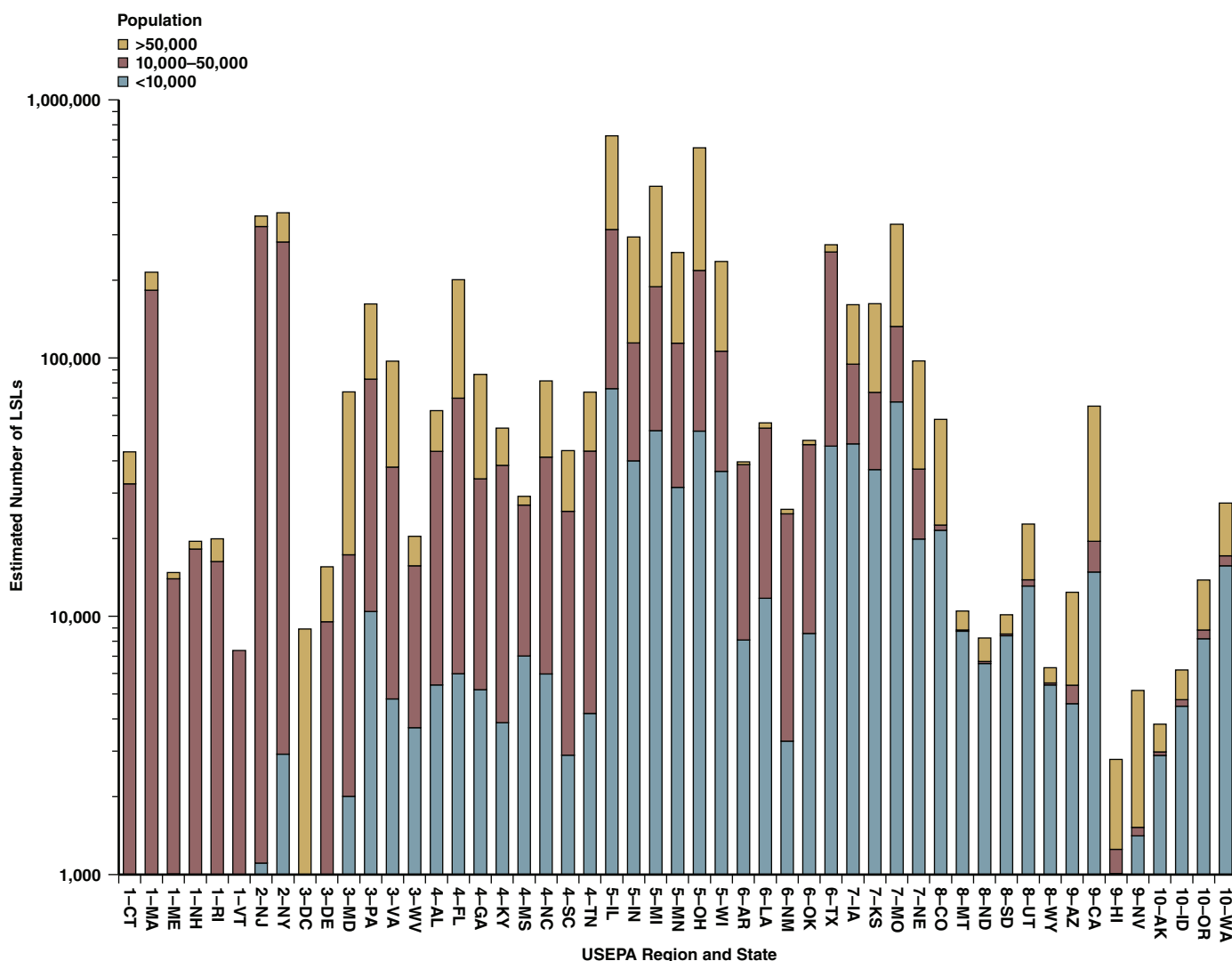


FIGURE 4 Range of national LSL total estimate



total national estimate of LSLs was calculated at 6.1 million. A breakdown by system size is summarized in Figure 2 and by regional group in Figure 3. The most LSLs in the United States occur in those utilities serving >50,000 people (2.8 million), followed closely by those serving 10,000 to 50,000 people (2.6 million), while those utilities serving <10,000 people have the fewest LSLs (0.7 million). Regionally, combined Regions 5 and 7 have the most LSLs by far, with 3.4 million. Regions 1 and 2 have about one million as do Regions 3 and 4. The other regions have well under one million LSLs.

FIGURE 5 Total number of LSLs estimated per population size range for each state^a



LSL—lead service line, USEPA—US Environmental Protection Agency

^aUS estimated number of LSLs from 2011 and 2013 surveys

It is important to caution that the analysis in this document was performed by grouped region. In order to convert to state occurrence, the same *k* and *N* values were assumed for each state in the grouped region. The state information is presented only to provide relative information on state variability.

The calculations in Table 4 reflect the use of the “best” value for *k* in Table 1. Using the “Min” and “Max” values, the resulting national estimate ranged from 5.5 million to 7.1 million, as shown in Figure 4.

Estimated number of LSLs in each state (by size and total). The number of LSLs by system size in each state was estimated using a similar approach for the national estimate as summarized in Table 4. These calculations multiplied the population data for each individual state from the SDWIS database, the estimated *N* from Table 3 (applied to all states within a regional group—see later example calculations), and *k* values for each region in Table 1 (column 5, applied to all states in a given USEPA regional group).

It is important to caution that the analysis in this study was performed by grouped region. In order to convert to state occurrence, the same *k* and *N* values were assumed to apply for each state in the grouped region. The state-specific estimates are presented only to provide relative information on state variability.

The number of LSLs estimated for each state is plotted in Figure 5. Table 5 contains the same information in a tabular form. The reader should note that the vertical scale in Figure 5 is logarithmic, and the estimated number of LSLs in Hawaii, Delaware, and all the states in USEPA Region 1 are all less than 1,000 LSLs for system sizes <10,000; consequently, these values are all off the scale (i.e., below the horizontal axis) in this figure. Performing the calculations

TABLE 5 Estimated number of LSLs by state and water system size

State	Water System Size (Population Served) ^{a,b}			
	<10,000	10,000–50,000	>50,000	All systems
USEPA Region 1				
CT	270	32,000	11,000	43,000
MA	650	180,000	32,000	220,000
ME	250	14,000	820	15,000
NH	290	18,000	1,300	20,000
RI	110	16,000	3,700	20,000
VT ^c	290	7,100	–	7,400
USEPA Region 2				
NJ	1,100	320,000	31,000	350,000
NY	2,900	280,000	84,000	360,000
USEPA Region 3				
DC	21	790	8,100	8,900
DE	970	8,500	6,000	16,000
MD	2,000	15,000	57,000	74,000
PA	10,000	72,000	79,000	160,000
VA	4,800	33,000	59,000	97,000
WV	3,700	12,000	4,700	20,000
USEPA Region 4				
AL	5,400	38,000	19,000	63,000
FL	6,000	64,000	130,000	200,000
GA	5,200	29,000	52,000	86,000
KY	3,900	35,000	15,000	53,000
MS	7,000	20,000	2,200	29,000
NC	6,000	35,000	40,000	82,000
SC	2,900	23,000	18,000	44,000
TN	4,200	39,000	30,000	74,000
USEPA Region 5				
IL	76,000	240,000	410,000	730,000
IN	40,000	75,000	180,000	290,000
MI	52,000	140,000	270,000	460,000
MN	32,000	83,000	140,000	260,000
OH	52,000	170,000	430,000	650,000
WI	36,000	70,000	130,000	240,000

State	Water System Size (Population Served) ^{a,b}			
	<10,000	10,000–50,000	>50,000	All systems
USEPA Region 6				
AR	8,100	31,000	1,000	40,000
LA	12,000	42,000	2,600	56,000
NM	3,300	22,000	1,000	26,000
OK	8,600	38,000	1,800	48,000
TX	46,000	210,000	17,000	270,000
USEPA Region 7				
IA	46,000	48,000	66,000	160,000
KS	37,000	37,000	89,000	160,000
MO	68,000	65,000	200,000	330,000
NE	20,000	17,000	60,000	97,000
USEPA Region 8				
CO	22,000	1,000	35,000	58,000
MT	8,800	95	1,600	10,000
ND	6,600	110	1,600	8,200
SD	8,400	130	1,600	10,000
UT	13,000	760	8,900	23,000
WY	5,400	93	800	6,300
USEPA Region 9				
AZ	4,600	830	7,000	12,000
CA	15,000	4,700	46,000	65,000
HI	1,000	240	1,500	2,800
NV	1,400	110	3,600	5,200
USEPA Region 10				
AK	2,900	96	840	3,800
ID	4,500	270	1,400	6,200
OR	8,200	660	5,000	14,000
WA	16,000	1,500	10,000	27,000
Total	720,000	2,600,000	2,800,000	6,100,000

LSL—lead service line, USEPA—US Environmental Protection Agency

^aNumber of LSLs rounded to two significant figures in each state and size

^bIt is important to caution that the analysis in this document was performed by grouped region. In order to convert to state occurrence, the same *k* and *N* values were assumed for each state in the grouped region. The state information is presented only to provide relative information on state variability.

^cThere were no water systems serving >50,000 reported by USEPA (2015) in Vermont.

by state in this manner results in the same estimated total number of LSLs nationwide as shown in Figure 4.

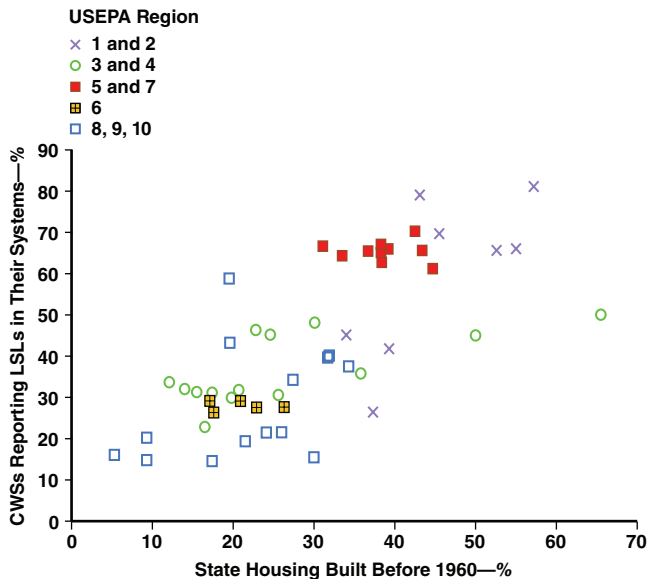
The intermediate calculations are not shown here, but the value of *M* estimated as described in Eq 1 was calculated using the same *k* values as given earlier and the *C* data from Table 2. The calculated *M* values for all states and system sizes were consolidated, resulting in a national total of 11,200 CWSs estimated to have LSLs somewhere in their systems.

Summary findings regarding the state and national LSL estimates.

Key summary statistics include the following:

- Total estimated number of LSLs in CWSs in all 50 states plus D.C.
 - 6.1 million
 - Projected range = 5.5. to 7.1 million
- National estimated total number of LSLs by population range served by the utility (Figure 2)

FIGURE 6 Percentage of homes built before 1960 versus percentage of CWSs with LSLs



Source: US Census 2015

CWS—community water system, LSL—lead service line, USEPA—US Environmental Protection Agency

The comparison is of houses in each state built before 1960 versus state populations served by CWSs that report having LSLs at some households in their systems.

over lead contribution from pipe, fittings, and solder resulted in less lead use in drinking water systems, including service lines and household plumbing. By 1986, USEPA had banned the use of any plumbing and associated materials that did not meet the USEPA-defined “lead-free” requirements (USEPA 1986).

Using US Census data (2015) for the age of homes in each state, and using 1960 as a cutoff date between “common” LSL use versus less common use, the results in Figure 6 compare the percentage of homes in each state older than 1960 with the percentage of CWSs in each state that have LSLs. The data from each state in this figure are plotted using the five regional groupings discussed elsewhere in this article.

Though not a statistically significant correlation ($R^2 < 0.5$), there does appear to be an increase in the estimated number of water systems with LSLs as the percentage of houses built earlier than 1960 increases. From a qualitative perspective, the use of the groups reflected in these calculations appears reasonable. Though not shown in Figure 6, similar conclusions result when 1970, 1950, or other decade target dates are used instead of 1960, with data shifted to the left (lower percentage of houses older than the target year) for periods before 1960 and shifted to the right for target dates more recent than 1960. In Figure 6, consistent with other data presented in this article, the highest percentages of systems with LSLs were in the Midwest in USEPA Regions 5 and 7. There were also two states in the Northeast (Region 2) estimated to have >80% of CWSs with LSLs (New York and New Jersey). At first glance, 80% of the CWSs having LSLs appears high. However, these states have nearly 60% of the homes being built before 1960. Therefore, it is not unreasonable that, if 60% of the homes in the state likely were originally constructed with LSLs, 80% of the CWSs would have at least some houses with LSLs.

SUMMARY

Results from two AWWA-sponsored surveys of US CWSs are presented describing the occurrence of LSLs in different regions of the United States for water systems serving different population sizes. The objective of this article was to estimate the number of water systems with LSLs and the approximate number of LSLs nationwide in each state by region and system size. The data presented also included information from the USEPA SDWIS database regarding the number of CWSs and population served by each in different states (USEPA 2015).

The survey results indicated that, on average, approximately 30% of the CWSs surveyed reported having some LSLs in their systems. Both full and partial LSLs were counted in this analysis. Results from the two surveys and the SDWIS database were combined to estimate the number of LSLs in each state and nationwide. The overall national estimate resulting from this effort was 6.1 million LSLs, with upper and lower boundaries on this estimate of 5.5 to 7.1 million (Figure 4).

The estimate prepared in conjunction with the initial promulgation of the LCR in 1991, as reported in the USEPA RIA (USEPA 1991), was 10.2 million. The original estimate was for a period more than two decades earlier than the period in this study. Assuming both estimates to be reflective of LSL presence for the reported periods, there are currently about four million fewer

- o Total LSLs in CWSs serving <10,000 population = 0.7 million (12% of the total)
- o Total LSLs in CWSs serving 10,000–50,000 population = 2.6 million (42% of the total)
- o Total LSLs in CWSs serving >50,000 population = 2.8 million (46% of the total)
- Total LSLs by regional group (Figure 3)
 - o Regions 1 and 2 = 1.0 million
 - o Regions 3 and 4 = 1.0 million
 - o Regions 5 and 7 = 3.4 million
 - o Region 6 = 0.44 million
 - o Regions 8, 9, and 10 = 0.25 million
- Estimated number of people with LSLs serving their homes
 - o Assume 2.4 to 3.6 people/LSL (Weston & EES 1990)
 - o 6.1 million estimated LSLs in the United States
 - o Population served by LSLs = 15 million to 22 million

The total population served by CWSs in the United States is 293 million (USEPA 2015), so the calculations here estimate that 5.0 to 7.5% of the US population is served by CWSs having a full or partial LSL.

Reality check of groupings using census data. Lead pipe was routinely used for service lines from the pre-1900s until about the 1930s. Between the 1930s and 1950s, concerns over lead pipe caused fewer LSLs to be installed during this period, though in many localities it was still used. Gradually, concern

reported LSLs. This reported reduction could be due to two major reasons. First, LSL replacement programs have reduced the prevalence of lead-containing plumbing in many water systems. Some utilities did only partial LSL replacements, which would not reduce the overall numbers since both full and partial lines are included in the totals. However, many utilities have had programs to remove the full LSL. It is also reasonable to assume that some of the reported reduction in the number of LSLs is due to better estimates and utility inventories of LSLs. The LCR resulted in many utilities obtaining better inventories of LSL presence after the original 1988 survey. As an example, utilities report going to neighborhoods where they originally thought LSLs were present, only to find there were not any (Brown et al. 2015). The reported reduction in LSL occurrence is a result of both replacement activity and better inventories.

The survey estimated that approximately 11,200 CWSs in the United States currently have LSLs in their systems, as compared with >15,000 estimated 26 years earlier (USEPA 1991). The estimated population with LSLs supplying their homes is 15 million to 22 million nationally. Overall the estimates indicate that in the last 26 years there has been a 40% reduction in the number of reported LSLs in the United States and a reduction of 30% in the number of CWSs that have LSLs. This reduction is either through full LSL replacement or better inventories.

ACKNOWLEDGMENT

The 2011 survey was originally tabulated, summarized, and evaluated by Kevin Dixon and then presented at the 2011 AWWA Water Quality Technology Conference. Clayton Cope (then at AWWA) collected and catalogued the 2013 survey data; the authors appreciate all the work done by him in collecting the data.

ABOUT THE AUTHORS



David A. Cornwell (to whom correspondence may be addressed) is president of Environmental Engineering & Technology Inc., 712 Gum Rock Ct., Newport News, VA 23606 USA; dcornwell@eetinc.com. He has been a technical advisor to AWWA during negotiations with the US Environmental Protection Agency (USEPA) for several regulatory developments affecting US drinking water facilities. Additionally, he prepared and reviewed formal comments,

guidance manuals, and supporting documents from AWWA on these regulations. Cornwell was honored with AWWA's A.P. Black Research Award. He received his PhD, MSE, and BSIE degrees from the University of Florida, Gainesville. Richard A. Brown is vice-president of Environmental Engineering & Technology Inc. Steve H. Via is the regulatory affairs manager in AWWA's office in Washington, D.C.

PEER REVIEW

Date of submission: 09/28/2015

Date of acceptance: 02/16/2016

REFERENCES

- Brown, R. & Cornwell, D., 2015. High-Velocity Household and Service Line Flushing Following LSL Replacement. *Journal AWWA*, 107:3:88. <http://dx.doi.org/10.5942/jawwa.2015.107.0012>.
- Brown, R.; McTigue, N.; & Cornwell, D., 2015. *Controlling Lead in Drinking Water*. Water Research Foundation, Denver.
- Brown, R.; McTigue, N.; & Cornwell, D., 2013. Strategies for Assessing Optimized Corrosion Control Treatment of Lead and Copper. *Journal AWWA*, 105:5:62. <http://dx.doi.org/10.5942/jawwa.2013.105.0066>.
- Dixon, K. & Via, S., 2011. Lead Service Lines: A Survey of Utility Replacement Practices. Proc. AWWA 2011 Water Quality Technology Conf., Phoenix.
- Frey, M., 1989. The AWWA Lead Information Survey: A Final Report. *Journal AWWA*, 81:9:64.
- Schock, M., 1989. Understanding Corrosion Control Strategies for Lead. *Journal AWWA*, 81:7:88.
- Schock, M. & Lytle, D., 2011 (6th ed.). *Internal Corrosion and Deposition Control. Water Quality and Treatment: A Handbook of Drinking Water*. McGraw-Hill, New York.
- US Census (United States Census Bureau), 2015. Decennial Census: 2010. www.census.gov/mp/www/cat/decennial_census_2010/ (accessed Aug. 22, 2015).
- USEPA (US Environmental Protection Agency), 2015. SDWISFED Drinking Water Data. <http://water.USEPA.gov/scitech/datait/databases/drink/sdwisfed/pivottables.cfm> (accessed Apr. 10, 2015).
- USEPA, 1991. *Final Regulatory Impact Analysis of National Primary Drinking Water Regulations for Lead and Copper* (1991.W.91.E.A). USEPA, Washington.
- USEPA, 1986. Interpretation of New Drinking Water Requirements Relating to Lead Free Plumbing Fittings and Fixtures. *Federal Register*, 62:163:44684.
- Weston, R.F. & EES (Economic & Engineering Services Inc.), 1990. *Lead Service Line Replacement: A Benefit-to-Cost Analysis*. AWWA, Denver.