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A study of lead service lines in California

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ABSTRACT

Under new regulations In the USA, all Community Water Systems (CWS) need to develop an inventory of their lead service lines (LSL) and determine those owned by their customers. This study will present an approach to address this issue that meets both the letter and the spirit of the law but is also practical and affordable. The first part examines the results of a survey of service lines conducted in California. Eleven million CWS-owned service lines were inventoried, but only four were LSL. The second part of the study was to examine the how California effectively outlawed LSL through the use of plumbing codes. The third part of the study was to determine if these codes had been as effectively implemented on the customer's service lines by examining the customer's service lines in Pasadena. No LSL were found.

Key words: customer service line, lead service lines, plumbing code, service line inventory

HIGHLIGHTS

- Field study of 108 customer service lines.
- Review of plumbing codes back to 1880.
- Survey of 11 million utility service lines.
- California' ban on lead plumbing.
- No lead service lines found.

1. INTRODUCTION

The United States Environmental Protection Agency (USEPA) has been regulating lead in drinking water for many years. In 2011, the United States Congress passed the Reduction of Lead in Drinking Water Act (RLDWA) and USEPA adopted the Lead and Copper Rule (LCR) to eliminate the use of lead plumbing and reduce lead exposure from corrosion.

Two of the central features of the LCR were the replacement of lead service lines (LSL) and the use of corrosion control technology when lead monitoring results exceeded certain thresholds. Corrosion control technology has been more widely used than LSL replacement. This was the case for several reasons. Where LSL was in use, a large portion of it was owned not by the Community Water Systems (CWS) but rather by the customer on whose property it lay. Further, replacing LSL are very expensive and challenging because it requires both the CWS and the customers to cooperate. It is worth noting that LSL do not release lead when the water is non-corrosive, either naturally or through the addition of corrosion inhibitors. Furthermore, lead can be released into the water when a single LSL is replaced. On the whole, for a long time, many have viewed that removing LSL creates greater risks of lead release and exposure than the use of corrosion control technologies.

However, following the events in Flint, Michigan, the USEPA proposed an update to the LCR, the Revised Lead and Copper Rule (LCRR). In the LCRR, there is a much greater emphasis on LSL removal and replacement. One aspect of the LCRR that has garnered much attention is creating an inventory of service lines with a particular focus on LSL. This effort includes the LSL on the customers' side of the meter. This approach has been highly controversial as it is challenging for CWS to determine the nature of customer-owned service lines. The LCRR included this requirement so the CWS could focus their efforts on the highest risk houses.

Potholing thousands of front lawns or cutting into sidewalks is impractical and expensive. There are also legal matters regarding the right of access to private property. The practicality of this aspect of the LCRR has been much discussed and debated. There is no need to reproduce that here, but suffice to say, there is great interest in finding a way to meet the intent of the LCRR in a cost-effective and practical fashion. This paper will attempt to lay out an approach that meets both the spirit and the letter of the LCRR regarding assessing customer service lines. The approach will be to study the service area of Pasadena Water and Power (PWP) to assess the likelihood that LSL had been used on the customer side of the meter. Data would be drawn from historical data and then the observed frequency of LSL use tested between the meter and the house using the water meter as the test site. While based in California, this approach, if successful, would be applicable in any area subject to the LCRR.

2. STUDY DESIGN

The first part of the study is to review the existing inventory of service lines in the PWP service area, including Pasadena itself and other nearby areas, including; Altadena, East Pasadena, and East San Gabriel. Generally, cities further west in the USA have been found to have fewer LSL than cities east of the Mississippi. New Jersey is a smaller State on the Atlantic Coast with groundwater and surface water long known to be corrosive to metal pipes. Cities like Newark have been shown to have large numbers of LSL. Newark would serve as a reference to compare Pasadena to a positive control for the presence of LSL. The second part of the study will examine the history of plumbing laws and ordinances in California. Historical laws and ordinances will be investigated to see what role they have played in determining the LSL inventory of California in general and PWP in particular. The LCRR allows for this approach as it states that the use of 'All documentation indicating the service line materials including construction and plumbing codes, permits, and existing records.'

Based on the results of these first two steps, a preliminary assessment of the risk of the presence of LSL can be made. To test this assessment, a subset of the highest risk houses, those most likely to have LSL between the meter in the parkway and the house, will be tested for the presence of LSL. Policy recommendations can be made based on the results of that study. In this paper, a proof of concept study will be conducted to see if this type of study is worth pursuing.

3. RESULTS

3.1. CWS lead service line inventory

In most CWS distribution systems, the mains are made of rigid materials such as cast or ductile iron. Where LSL are used, the lead pipe has a brass coupling at one end, which connects to the main directly through the corporation stop at one end and to the meter at the other end. However, if an iron service line is used, such as a galvanized pipe or wrought-iron pipe, a short length of more flexible pipe is used to connect the service line to the main. These are variously known as 'bends,' 'pig-tails,' 'goosenecks,' 'whips,' or simply connection pipes and were commonly made of lead before 1930. Still, other materials replaced lead even before the passage of the RLDWA. The RLDWA banned the installation of LSL and, with the adoption of the LCR, CWS began to actively target the removal of LSL.

The California legislature recently passed two bills, Senate Bill 1398 (2016) and Senate Bill 427 (2017), which required all CWS to compile an inventory of all service lines and identify the material from which they were made by July 1, 2018. CWS were further required by July 1, 2020 to propose a schedule to replace all the known lead user service lines and user service lines constructed of an unknown material.

These pipes were not recorded in the inventory as service lines but as 'fittings,' but the service line's material needs to be recorded. Only the service line owned by the CWS between the main and the meter needs to be recorded. CWS that had service lines initially reported in 2016 were required to determine the nature of the pipe material and report that by the end of 2018. The results of the study are shown in Table 1. A second inventory was collected in 2020; the results are also shown in Table 1. As can be seen, in 2016 and 2018, over 11 million service lines were inventoried. In 2018, only 136 service lines were known to contain lead. These were found in only three CWSs, and one of those only had one LSL. About 7% of the service lines were of unknown material (860,962), and just over 33,000 short lead fittings were found, i.e., pig-tails and goose necks. Two years later, however, while the total number of service lines remained essentially the same, the number of service lines of unknown material decreased dramatically (92,172).

Table 1 | Lead service line inventory of California

Date	November 2018	October 2020
Inventoried	11,270,203	11,301,495
Unknown material	860,962	92,172
Lead fitting not on LSL	33,039	25,220
Lead service lines	136	4
CWSs with LSL	3	3
CWS 1	1	1
CWS 2	85	2
CWS 3	50	1

Following an investigation by CWS, the number of lead fittings decreased (25,220), but most importantly, the number of LSL decreased to just four. In other states, there are thousands, in some cases tens of thousands of LSL, while in California, there are effectively none. PWP, of course, participated in both of these service line inventory efforts and found no LSL and no lead pig-tails. PWP, however, did have records indicating that it had, before 1930, used lead pig-tails extensively but no LSL. After 1930, PWP ceased using lead pig-tails.

3.2. City of Newark

City of Newark, New Jersey, also prepared a survey of its service lines about the same time. The State of New Jersey estimated in 2019 that there were 350,000 LSL, the fifth-highest number of LSL in the USA, which were concentrated in three areas, the central part of the State around Trenton, the north part of the State around Newark, and with a few areas in the south near Camden. This use of lead is not unusual as many of the surface and ground waters found on the mid-Atlantic coast of the USA are corrosive. Lead pipes were highly corrosion resistant compared to other types of pipes before the widespread use of copper. An extreme example is Philadelphia, where LSL were required by city ordinance in 1916 to be used before the adoption of the RLDWA to prevent excessive water loss due to corrosion of galvanized pipes. Newark, New Jersey, had prepared a detailed inventory of service lines which was downloaded for this study. It contained, among many other items, the account number for each service line, the year of installation, and the material from which the service line was made. The results of this survey are shown in Table 2 and Figure 1. There were 36,074 results. Some did not have the material, some did not have the installation date, and a few had neither, but a sizable majority had both. There were 18,404 LSL, 15,281 of which had an installation date. If the number of installations for copper and lead are plotted over time, it can be seen that the use of LSL in Newark dropped dramatically after 1930.

Table 2 | Service line inventory of Newark New Jersey

Total service line	36,074
No date	11,313
No material	5,583
Lead	18,404
Lead and date	15,281
Copper	11,286
Copper and date	8,737
Ductile iron	92
Ductile iron and date	71
Hydrant	150
Hydrant & date	27

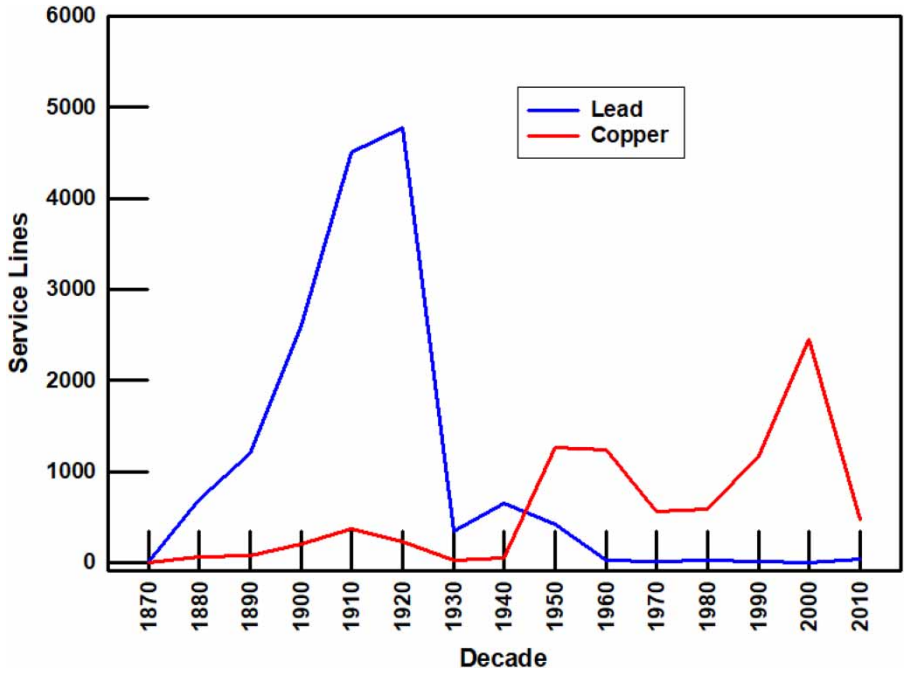


Figure 1 | Service line inventory installation by decade in Newark, New Jersey.

The State of New Jersey Department of Environmental Protection determined that many, if not most, of the LSL in New Jersey, were installed before 1940 (New Jersey Water Works 2019). The decrease in the number of LSL in Newark following 1930 is partly due to a slowdown in the construction of new houses during the Great Depression and World War II (WWII). However, as home construction increased following WWII, most homes were constructed with copper services lines instead of lead, even though LSL were legal in New Jersey until 1986. Clearly, in the case of Newark, New Jersey, the use of LSL was primarily in the years before 1930, which, given the widespread use of LSL there, offers a reasonable estimate of when LSL, if they were ever used at all in California, would have been used most. This practice parallels PWP's practice with lead pig-tails.

3.3. Lead pipe economics

There are several reasons why lead fell out of favor as a plumbing material for service lines. First, lead pipes are often more expensive than iron pipes per-foot for any internal diameter. In 1916, a study published in Engineering News showed that lead pipes were considerably more expensive (Engineering News 1916) than equivalent iron pipes. Lead is much softer than iron, so to give it enough strength of the same internal diameter, lead pipes are about twice as thick as an equivalent piece of iron or copper pipe for the same internal diameter. The superior corrosion resistance of lead pipes, mainly external corrosion from the soil, and the malleability of lead made them a better choice for at least the pig-tails, if not the entire service line from a mechanical perspective. However, while it had been known for many centuries that lead could be very toxic, the exact connection between lead corrosion and lead exposure was unclear. Many lead pipes did not corrode or release lead, while others did. Sometimes the same pipe might corrode one time of the year and not another. However, as the chemistry of lead pipe corrosion was better understood, the popularity of lead service pipes declined thanks to the development of the Langelier Index and other similar techniques. The availability of copper and more flexible iron pipes also pushed lead pipes from the market.

3.4. Historical records

To create the necessary context to assess the results of these two studies. California State Legislature created the Board of Health in 1870. It consisted of seven physicians throughout the State who held office for four years. It was an entirely advisory body with only one employee, the secretary, but it had broad powers to make investigations. One of the first was an investigation into lead poisoning in Sacramento caused by the corrosion of

lead 'house communications pipes' (i.e., service lines) in 1871. One sample collected had 0.25 grains of lead per gallon (or 4,300 μg/L). Several individuals became highly ill with classic symptoms of acute lead poisoning such as colic and blue gums. The State Board of Health recommended against the use of lead for plumbing and instead urged the use of iron pipe (California Board of Health 1871).

A few years later, the State Legislature passed a bill in 1883, SB 132, which authorized local counties and cities to create their own Boards of Health and that those boards would have the authority to regulate plumbing. The bill does not offer any details on any practical aspect of what a local plumbing law would look like. While SB 132 was being considered, the City of San Francisco was simultaneously greatly expanding their local plumbing law to include all aspects of the art and science of plumbing as understood in the early 1880s. Lead was not listed as an approved plumbing material except as caulking with oakum or as ferrules. Other cities copied San Francisco's plumbing laws, making modifications over the years. Most added an exception for a short length of lead pipe to connect longer sections of iron or steel pipe. These laws and ordinances established one set of rules for both the delivery of potable water and the removal of sewage; there were not separate schedules for each as there are today.

3.5. Indoor plumbing and public health

In 1900, diarrheal diseases such as typhoid fever, cholera, and dysentery were a significant cause of death in the United States (North 1905). Figure 2 shows how the development of indoor plumbing, with water delivery into the house in pipes, impacted mortality. The graphs show the deaths per 100,000 caused by diarrhea and typhoid fever between 1900 and 1924 and total spending on enameled sanitaryware, used as a surrogate for indoor plumbing expenditures. This dramatic and vital drop in mortality is generally credited to the application of chlorine, both in treating surface water for domestic use and in treated sewage discharges to surface waters, as well as sand filtration of surface waters. Although perhaps less well documented, the other revolution in public health occurring during this period was the expansion of indoor plumbing. Indoor plumbing was rare in the USA before 1900, and even by 1940, 45% of surveyed homes lacked complete indoor plumbing (Ballanco 2010). Figure 2 shows the annual mortality rates for diarrheal diseases and typhoid fever in particular. This graph shows the increase in the use of indoor plumbing in the 20th century (United States Census Bureau 1990; (Federal Reserve Bank 2022). While crude, these figures support the general notion that the dramatic fall in

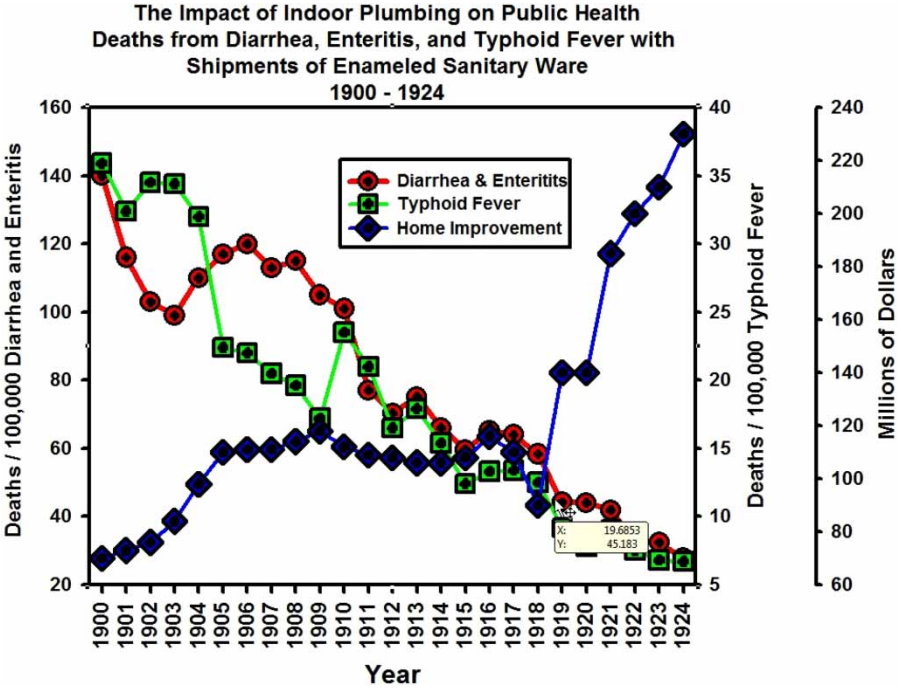


Figure 2 | The impact of indoor plumbing on public health deaths from diarrhea, enteritis, and typhoid fever with shipments of enameled sanitaryware 1900–1924.

diarrheal diseases during the period was caused by the increased availability of water free from enteric pathogens and the ability to use this water indoors in large quantities. Sanitary water could then be used for various public health functions, flushing toilets, washing clothes, cleaning food, bathing, and so forth.

Figure 2 is crucial as it shows that indoor plumbing for water delivery was primarily a phenomenon of the 20th century. Thus municipal plumbing laws did not directly address them until well into the 20th century.

3.6. Ban on lead

Perhaps in part to address this issue of LSL more directly, in 1894, the State Board of Health wrote in its biennial report to the California legislature: 'The house-communication pipes are generally of lead. Hygiene cannot approve of their employment, for they are liable to be acted upon, especially by soft water. In consequence, there may be danger of lead poisoning of the customer.' As a result, local plumbing ordinances began to become more explicit in identifying that their ordinances applied to both sewage and source water plumbing, including a *de facto* ban on lead pipes. None of these ordinances explicitly establish a positive ban on lead pipes of any kind, much less explicitly on service lines that could have said: 'lead pipes may not be used'. Instead, they established a negative, implicit ban. Going back to San Francisco's plumbing law of 1880, all of these plumbing ordinances have a schedule of approved plumbing materials, and lead pipes are not on that list. As the various plumbing ordinances evolved, this approach became more transparent and explicit.

Using Pasadena as an example, the city was founded in 1875 and incorporated in 1882. In 1892 the city adopted Ordinance 206 for 'Prescribing rules and sanitary regulations for the City of Pasadena: Also regulating the Art of Plumbing with the City of Pasadena.' Section 4 mandates the use of either cast iron pipes and fittings with specified weight per length or wrought-iron pipes and fittings of the Durham system (which uses threaded pipes which are galvanized instead of lead caulk). Lead is not explicitly banned, but it is not included, either. In Section 14, water supply is addressed in an uncharacteristically direct fashion for the time: 'All water closets within the building must be supplied with water from a separate tank or cistern, in no case connected directly to the water main.' It further notes that the tank must have no less than four gallons of capacity, and the 'flushing pipe' must be no less than 1.25 inches in diameter. This section also notes: 'When the water supply is not ample for proper flushing of closets, the Inspector of Building and Plumbing may, at his direction, order the erection of a tank or cistern into which water may flow or into which it may be pumped, and said order shall be at once complied with.' Section 16 requires lead caulking with oakum and lead connecting pipes between iron pipes. The ordinance assumes that potable water is available from mains in the street through service lines but does not state this explicitly. The fact that this ordinance applied to the supply side was not made explicit until 1930 when the ordinance was amended to read:

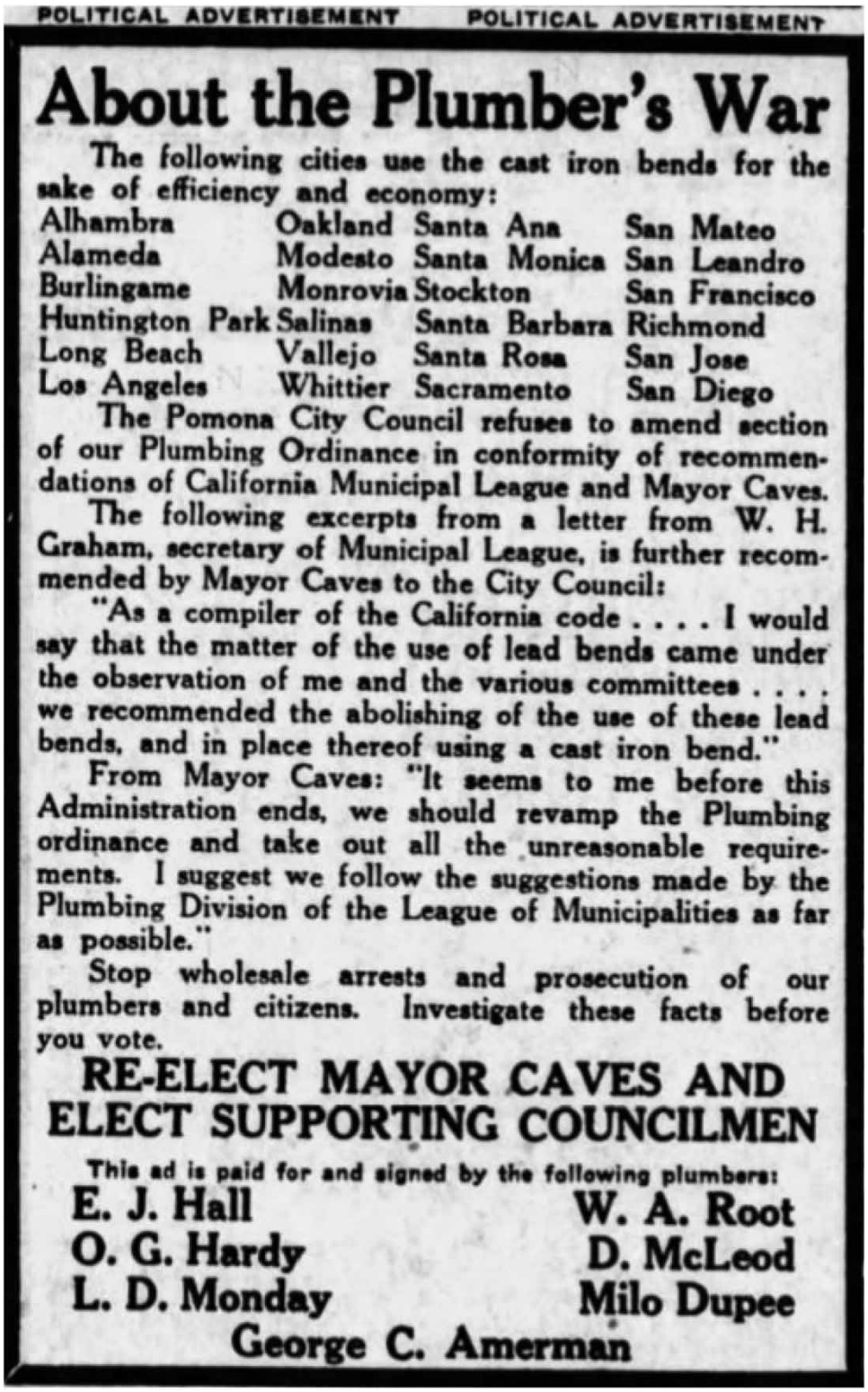
'(k) 'Plumbing' shall be deemed to mean the art and work of installing in buildings the pipes, fixtures, and other apparatus for bringing in the water and gas supply and for removing liquid and water-carried wastes. The said pipes, fixtures, and apparatus shall, be deemed to mean and include the water supply distributing pipes, the fixtures and fixture traps, the soil, waste and vent pipes, the house drain and house sewer, the stormwater drainage, with their devices, appurtenances, and connections within or directly serving the building, and the gas supply pipes.'

This trend of *de facto* bans on lead pipe and plumbing material by excluding them from a schedule of approved plumbing materials became increasingly explicit and detailed over the years. In 1964 Los Angeles County had its building ordinance, which included Table A, which listed all approved plumbing materials. All materials are iron, copper, or brass, except 'bends' and traps, which could be lead.

In the end, California had effectively banned the vast majority of lead plumbing, especially service lines, over 120 years ago. LSL were undoubtedly installed in some locations, as the 2018 inventory indicates. However, following the passage of the LCR and other lead plumbing statutes and regulations, CWSs began removing LSL. The LCR has LSL removal provisions, and it would appear that CWSs implemented these following 1986. The only exception was the bends, which appear to have disappeared as a practical matter around 1930 as other materials became available. The same market forces that resulted in the dramatic decline in the use of LSL in New Jersey in the 1930s led to the abandonment of lead pig-tails in California, even though the use was entirely legal in both cases.

In the 1920s, the California Municipal League (CML) had a Plumbing Division. The Plumbing Division developed recommendations for modifications to local plumbing ordinances. One of those recommendations was to eliminate the use of lead bends. In 1930 the City of Pomona City Council proposed to amend its plumbing

ordinance to allow iron-based bends, following the recommendation of the CML. This proposal was opposed by the majority of the city council and became a campaign issue in the municipal election that year (Figure 3). This proposal emerged from the growing body of evidence of the lethality of lead from lead plumbing. For example, in 1927, the Bureau of Labor Statistics published Bulletin 426, titled 'Deaths from Lead Poisoning .'While it generally focused on occupational and industrial deaths, the report notes many deaths from lead poisoning in



POLITICAL ADVERTISEMENT POLITICAL ADVERTISEMENT

About the Plumber's War

The following cities use the cast iron bends for the sake of efficiency and economy:

Alhambra	Oakland	Santa Ana	San Mateo
Alameda	Modesto	Santa Monica	San Leandro
Burlingame	Monrovia	Stockton	San Francisco
Huntington Park	Salinas	Santa Barbara	Richmond
Long Beach	Vallejo	Santa Rosa	San Jose
Los Angeles	Whittier	Sacramento	San Diego

The Pomona City Council refuses to amend section of our Plumbing Ordinance in conformity of recommendations of California Municipal League and Mayor Caves.

The following excerpts from a letter from W. H. Graham, secretary of Municipal League, is further recommended by Mayor Caves to the City Council:

"As a compiler of the California code . . . . I would say that the matter of the use of lead bends came under the observation of me and the various committees . . . . we recommended the abolishing of the use of these lead bends, and in place thereof using a cast iron bend."

From Mayor Caves: "It seems to me before this Administration ends, we should revamp the Plumbing ordinance and take out all the unreasonable requirements. I suggest we follow the suggestions made by the Plumbing Division of the League of Municipalities as far as possible."

Stop wholesale arrests and prosecution of our plumbers and citizens. Investigate these facts before you vote.

RE-ELECT MAYOR CAVES AND ELECT SUPPORTING COUNCILMEN

This ad is paid for and signed by the following plumbers:

E. J. Hall
O. G. Hardy
L. D. Monday
W. A. Root
D. McLeod
Milo Dupee
George C. Amerman

Figure 3 | Political advertisement for a candidate for the Mayor of Pomona in 1930.

residential settings, particularly in agricultural and rural areas lacking any source of lead other than lead pipes. This trend was particularly true for women in these rural areas. The authors note several instances where: 'The death…was attributed to drinking water drawn through a lead pipe.' Reports like this added to widespread concern with drinking water from lead pipes.

The fact that there is only a handful of LSL in California in the early 21st century while other states have tens of thousands is not surprising given the regulatory environment. Water purveyors were subject to the building ordinances, so they would not have been allowed to use LSL, which was enforced given the results of the service line inventory, at least for CWS.

3.7. Customer service lines

The one unanswered question is the status of service lines on the customers' side of the water meter. Is it possible that thousands of CWS installed over 11 million service lines in California without any significant number of them being lead, while at the same time there were many LSL installed on the customers' side of the meter? This situation seems rather unlikely given that the same plumbing ordinances were in force for both the contractors installing service lines for CWSs and private housing contractors. However, it is at least theoretically possible that when houses were being constructed, the plumbing contractor installed LSL even though the local CWS installed other types of service lines and local ordinances did not allow it. In the Newark database, 1,757 service lines were a mix of copper and lead. In total, 84 partial LSL from the main to the curb and 324 from the curb to the meter. None of those cases had the service lines been installed in a mixed fashion. The partial installation resulted from partial service line replacement, not original construction. It is important to note that in New Jersey, and in many States where LSRs are common, service lines have two parts: the main to the curb stop and one from the curb stop to the meter. The meter is typically in the basement of the house with a furnace room. In California, meters are by the curb between the house and the main. So if Newark is any model for California, LSL can exist between the meter and the house if partial service line replacement has occurred. Since PWP has routinely updated its service lines, partial service line replacement did occur.

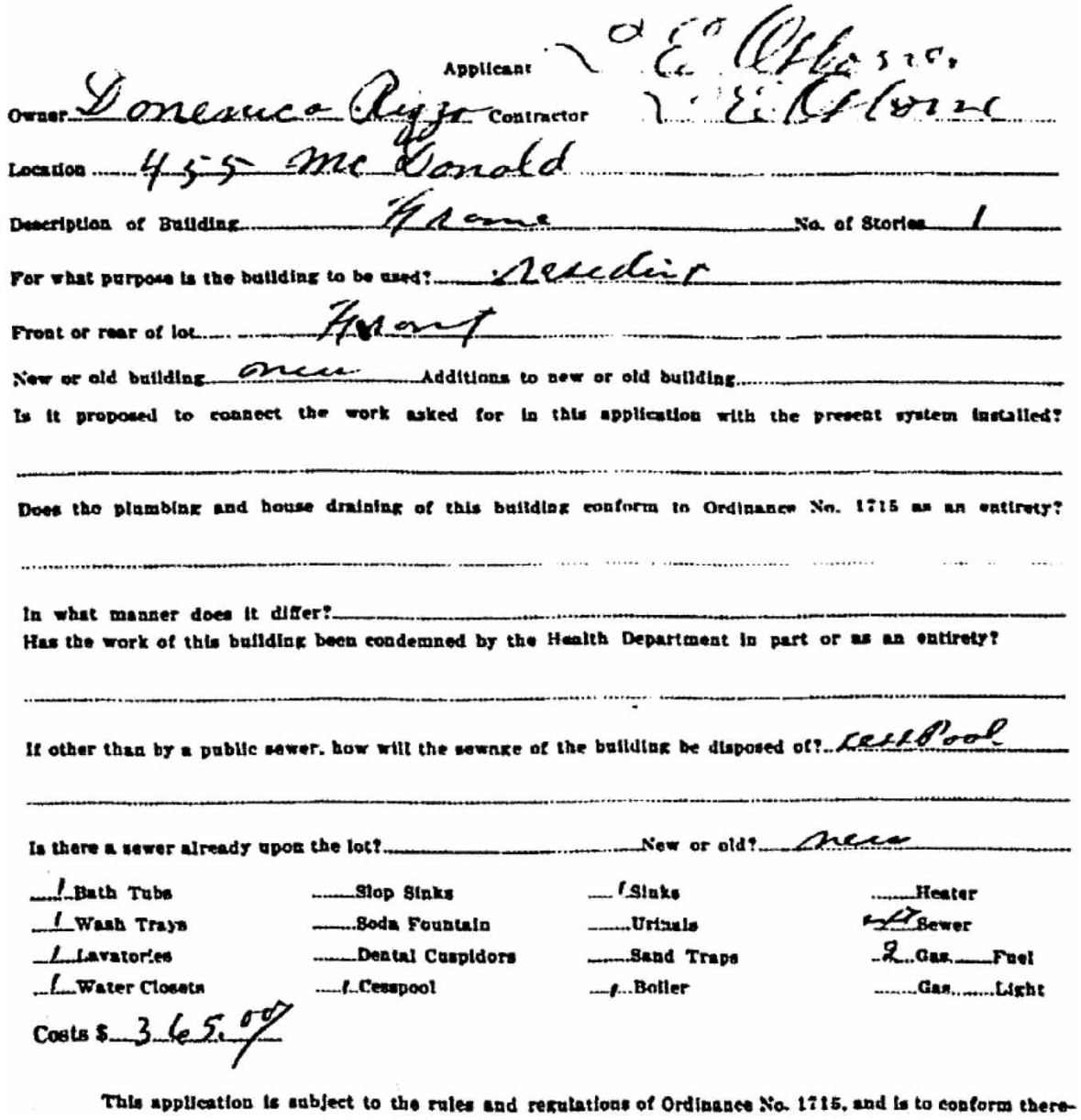
The difficulty, of course, is that it is a very intensive and complex effort to determine the type of material used in the service line between the meter and the house. Again using Newark as a model, the vast majority of any LSL would have been installed before 1930. One approach might be to examine pre-1930 building records. However, these records are not often available, may not be entirely legible, and often do not record sufficient detail to make any determination. Building inspectors often confirmed that the construction was consistent with the plumbing code without providing additional information. The items to be inspected are listed, but nothing is shown about the nature of the materials. At the bottom, it simply states, 'This application is subject to the rules and regulations of Ordinance 1715 and is to conform there' (Figure 4). This level of information would be of no use for the type of efforts needed to comply with the LCRR. This situation only leaves CWS seeking to comply with the LCRR with one option, to physically examine the service lines of its customers and determine the material.

3.8. Housing population at risk for having LSL

Given the experience of both the City of Newark and the City of Pasadena with lead plumbing, both used few lead materials after 1930; if any LSL are to be found in Pasadena, it would be among the pre-1930 houses. PWP has approximately 38,000 service connections, and about 10,000 of those are for buildings built before 1930. Further, several houses were constructed before 1892, when the City's plumbing ordinance was adopted. These pre-1892 houses would be at the most significant risk for having LSL. A study conducted in 1900 found that the LSL was primarily found in larger cities (Baker 1897). In 1900, Pasadena only had a population of 9,100. Thus, even 120 years ago, it was unlikely to have employed LSL. Indeed, the data from New Jersey would support this point; LSL are even today found around the three major urban areas of Camden, Newark, and Trenton and not too many other places.

3.9. Testing

A simple, low-cost technique was a colorimetric method. A low pH solution is applied to the pipe, and a reagent is added. Some lead is solubilized, which reacts with the reagent, producing a color. PWP purchased a 'Lead Check' product from 3M for this study. It consists of a tube containing a tartaric acid solution. This technique has been used for many years and is listed in the USEPA's 'Three T's' documents for lead in water minimization (USEPA 2022). When the tube is crushed, the solution is mixed and absorbed into a swab at the end of the tube. The swab



Applicant E. E. Olson

Owner Domenico Ruggo Contractor E. E. Olson

Location 455 McDonald

Description of Building Frame No. of Stories 1

For what purpose is the building to be used? Residence

Front or rear of lot Front

New or old building New Additions to new or old building

Is it proposed to connect the work asked for in this application with the present system installed?

Does the plumbing and house draining of this building conform to Ordinance No. 1715 as an entirety?

In what manner does it differ?

Has the work of this building been condemned by the Health Department in part or as an entirety?

If other than by a public sewer, how will the sewage of the building be disposed of? Cesspool

Is there a sewer already upon the lot? New or old? New

1 Bath Tubs	Slop Sinks	1 Sinks	Heater
1 Wash Trays	Soda Fountain	Urinals	Sewer
1 Lavatories	Dental Cuspidors	Sand Traps	2 Gas Fuel
1 Water Closets	1 Cesspool	1 Boiler	Gas Light

Costs $ 3.65.00

This application is subject to the rules and regulations of Ordinance No. 1715, and is to conform there-

Figure 4 | Construction Permit Application for Plumbing in Pasadena Pre-1940.

is dabbed onto the pipe. Lead is present if it turns a red color (Pb_3O_4 – Sindoor or Minium). This process was tested out by PWP staff. A lead pig-tail was used as a positive control. Figure 5 shows the solution as it was applied to the lead pig-tail. A clear and distinctive red color was produced. Figure 5 shows the broken tube, the swap, and the colored spot on the lead pig-tail where the solution was applied to the paper positive controls. The solution was swabbed onto a stainless steel bolt as a second negative test.

3.10. Study design

In Pasadena, as with most of California, the water meter is located between the sidewalk and the street in a concrete box in the public right of way. The customers' and the CWS service lines meet at the water meter, and both are exposed inside the meter box. It is possible to open the top of the meter box and test the short portion of the service line immediately adjacent to the meter itself. There is, of course, a brass coupling at the end of the service line, which would be unproductive to test. It would be essential to test the actual pipe beyond the brass fitting.

Further, testing the pipe would primarily occur with the tester being on their knees, if not lying flat. Additionally, it would take some effort to take a good photograph of the tested portion of the pipe to record the test results.

Figure 5 | Negative quality control check on stainless steel.

Instead of testing thousands of separate houses, it would be most efficient to sample a representative sub-sample of the entire population of service lines. If 1% of the pre-1930 service lines installed between the meter and the house were tested, that would be 100 service lines. If 100 service lines were tested, that would give a reasonable estimate of the frequency of occurrence of LSL in the PWP's service area. The standard of 1% is arbitrary but a reasonable starting point for a first of its kind field study.

3.11. Proof of concept

Five houses were selected to see if this sort of approach would work. They were at 506 Summit Ave., 514 Cypress Ave., 620 Blake Street, 801 Sunset Ave., and 824 Oakland Ave. All four houses were built in 1885, just three years after the city was incorporated and seven years before Pasadena adopted its plumbing law. This scenario would be something of a worst-case scenario. This time was when LSL were most commonly installed in the USA and before any legal restrictions existed which might have prevented LSL use. On June 29th, 2021, PWP staff visited these five locations. As it turned out, the meter at the Blake Street location was inaccessible; the meter was on the customer's property. The test at summit was also negative, but the photograph did not produce a useful image. In Figure 5, not only is the tartaric acid solution not red, but the underlying copper color of the pipe is visible.

3.12. Test houses

Houses for the full-scale field study were selected from the houses built between 1881 and 1930. For each calendar year, two houses were selected. The two houses could not be on the same street or postal code. No houses were constructed between 1882 and 1899, and only one was constructed in 1889, so only one house constructed in that period was tested. The four houses tested in the proof of concept phase were re-tested to compensate for this deficit. PWP's service includes all of the City of Pasadena but extends beyond it. Parts of the neighboring municipalities of the City of Los Angeles and the City of San Marino are also served as parts of the unincorporated neighborhoods of Altadena, East Pasadena, and East San Gabriel. Special efforts were made to ensure that at least one sample house was tested in each jurisdiction to address this situation. Only single-family detached dwellings were tested.

Additionally, 11 post-1930 houses were selected for testing. Efforts were made to ensure as many parts of the service area were represented. However, the distribution of sample locations was not uniform. Higher-risk houses were more common on the west side of the distribution area, and large portions of the city were either non-residential or dominated by multi-unit housing. Figure 6 shows a map of PWP's service area with the locations of the sample houses presented.

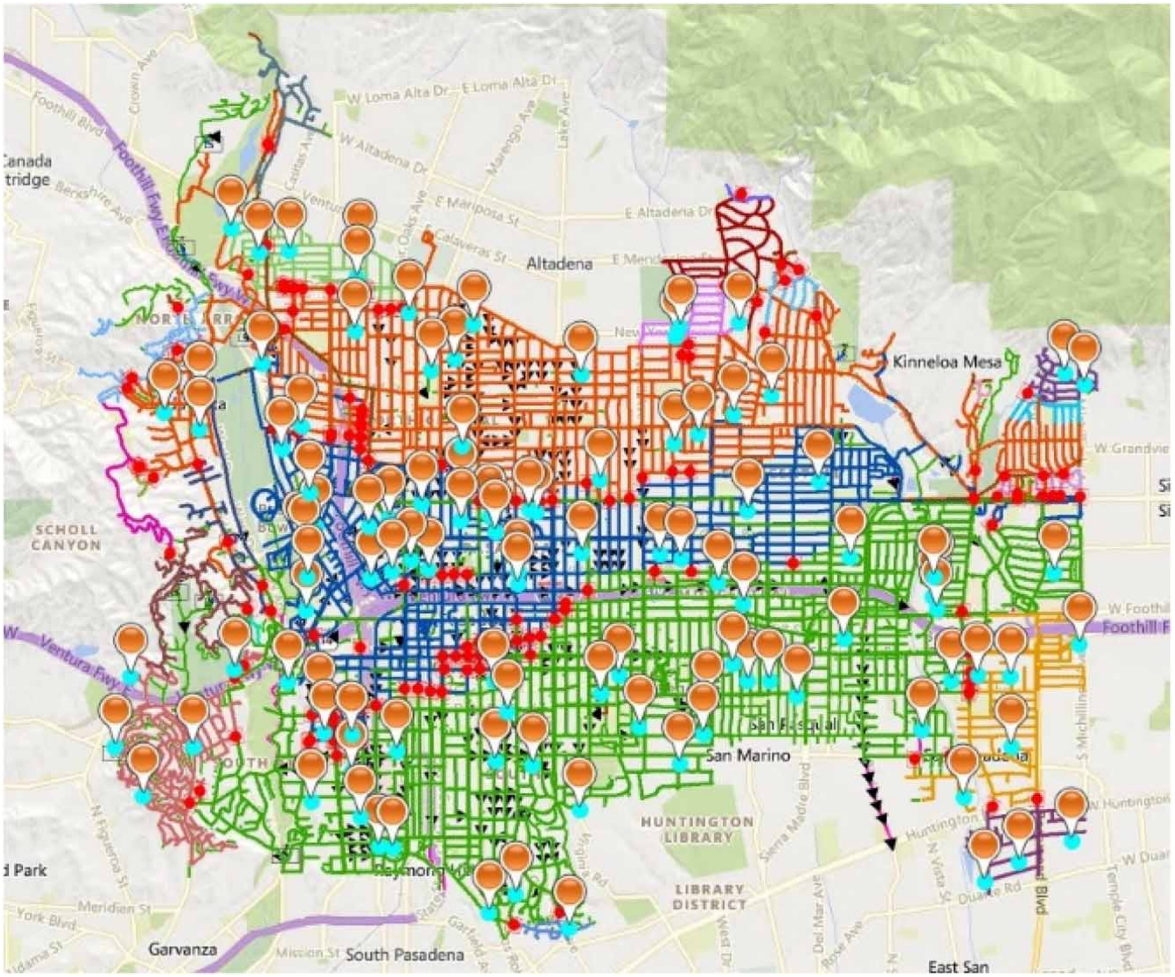


Figure 6 | Map with sample locations.

3.13. Testing procedure

Each meter box was opened from the top, and the entire box roof and lid was removed. The interior was cleaned to remove bulk debris and remove insects. The pipes were sprayed with water and wiped down with a paper towel. A piece of paper with the sample number was placed inside the pipe to be tested. The swab test was performed, and a photograph was taken. Notes were taken about the condition of the pipes and assessed against the following criteria:

a. Copper pipes were expected to be orange in color unless there was oxidation, in which case a patina of either malachite or azurite may be present. The pipe joints should be soldered. The pipes themselves should not be visibly corroded.
b. Plastic pipes should be white, non-metallic, have no visible corrosion, and blue glue may be visible.
c. Iron pipes will be colored orange to brown, have threaded joints, and be visibly corroded.
d. Lead pipes will be grey, should have no external corrosion, have either 'wiped joints' or be joined by a brass coupling or union, have a significantly wider outside diameter, and have a positive red reaction to the swab test. Since lead is significantly softer and weaker than other pipe materials when used, it was produced with a much thicker wall to add strength.

3.14. Results

PWP examined 133 meter boxes. All of the service lines on PWP's side of the meter were copper except for one plastic pipe. On the customers' side of the meter, the status of 24 locations could not be determined as the meter was either flush up against the meter box wall or a service clamp (Dayton Clamp) obscured the view. Of the 108 service lines on the customer's side of the meter examined by PWP staff, none were lead, 69 were copper, 24 were

iron or steel, and 15 were plastic. The results are displayed in more detail in Attachment 1. The goal of this portion of the LCRR is to reduce the likelihood of lead corrosion from LSL by emphasizing the removal of LSL. Corrosion control technology is minimized in the LCRR as only zinc orthophosphate is allowed. This unfortunately cannot be used in areas like Pasadena because of Waste Load Allocations from Total Maximum Daily Load (TMDL) which have been incorporated into local stormwater discharge permits. There are TMDLs for both phosphorus and zinc in Los Angeles County.

4. CONCLUSIONS

Within the context of the regulatory history of plumbing ordinances in California, a *de facto* ban on LSL was established at least 120 years. There is ample evidence that CWS did not use LSL; it seems reasonable to conclude that there is little likelihood that the PWP's customers have LSL. PWP believes that a field study of 100 pre-1930 houses, especially pre-1892 houses, would provide sufficient evidence to determine if any private services were lead or not.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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