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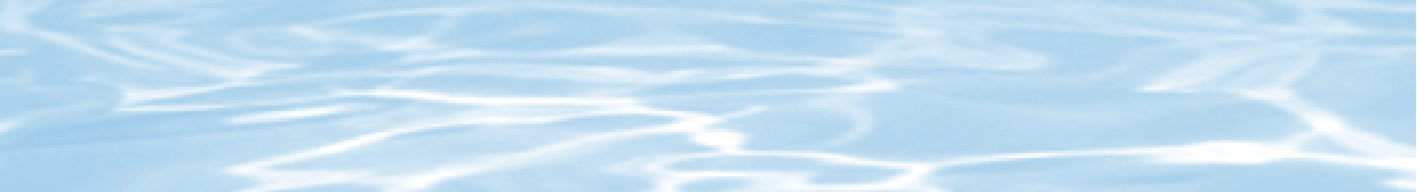
Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues

Subject Area:
Infrastructure Reliability



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The Awwa Research Foundation (AwwaRF) is a member-supported, international, nonprofit organization that sponsors research to enable water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to consumers.

The Foundation's mission is to advance the science of water to improve the quality of life. To achieve this mission, the Foundation sponsors studies on all aspects of drinking water, including supply and resources, treatment, monitoring and analysis, distribution, management, and health effects. Funding for research is provided primarily by subscription payments from approximately 1,000 utilities, consulting firms, and manufacturers in North America and abroad. Additional funding comes from collaborative partnerships with other national and international organizations, allowing for resources to be leveraged, expertise to be shared, and broad-based knowledge to be developed and disseminated. Government funding serves as a third source of research dollars.

From its headquarters in Denver, Colorado, the Foundation's staff directs and supports the efforts of more than 800 volunteers who serve on the board of trustees and various committees. These volunteers represent many facets of the water industry, and contribute their expertise to select and monitor research studies that benefit the entire drinking water community.

The results of research are disseminated through a number of channels, including reports, the Web site, conferences, and periodicals.

For subscribers, the Foundation serves as a cooperative program in which water suppliers unite to pool their resources. By applying Foundation research findings, these water suppliers can save substantial costs and stay on the leading edge of drinking water science and technology. Since its inception, AwwaRF has supplied the water community with more than $300 million in applied research.

More information about the Foundation and how to become a subscriber is available on the Web at **www.awwarf.org.**

Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues

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FOREWORD

The Awwa Research Foundation is a nonprofit corporation that is dedicated to the implementation of a research effort to help utilities respond to regulatory requirements and traditional high-priority concerns of the industry. The research agenda is developed through a process of consultation with subscribers and drinking water professionals. Under the umbrella of a Strategic Research Plan, the Research Advisory Council prioritizes the suggested projects based upon current and future needs, applicability, and past work; the recommendations are forwarded to the Board of Trustees for final selection. The foundation also sponsors research projects through the unsolicited proposal process; the Collaborative Research, Research Applications, and Tailored Collaborations programs; and various joint research efforts with organizations such as the U.S. Environmental Protection Agency, the U.S. Bureau of Reclamation, and the Association of California Water Agencies.

This publication is a result of one of those sponsored studies, and it is hoped that its findings will be applied in communities throughout the world. The following report serves not only as a means of communication the results of the water industry's centralized research program but also as a tool to enlist the further support of the nonmember utilities and individuals.

Projects are managed closely from their inception to the final report by the foundation's staff and large cadre of volunteers who willingly contribute their time and expertise. The foundation serves a planning and management function and awards contracts to other institutions such as water utilities, universities, and engineering firms. The funding for this research effort comes primarily from the Subscription Program, through which water utilities subscribe to the research program and make an annual payment proportionate to the volume of water they deliver and consultants and manufacturer subscribe based on their annual billings. The program offers a cost-effective and fair method for funding research in the public interest.

A broad spectrum of water supply issues is addressed by the foundation's research agenda: resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide the highest possible quality of water economically and reliably. The true benefits are realized when the results are implemented at the utility level. The foundation's trustees are pleased to offer this publication as a contribution toward that end.

David E. Rager	Robert C. Renner, P.E.
Chair, Board of Trustees	Executive Director
Awwa Research Foundation	Awwa Research Foundation

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EXECUTIVE SUMMARY

BACKGROUND AND APPROACH

Implementation of the Lead and Copper Rule (LCR) has resulted in significant reductions in first liter standing lead levels measured at the tap in the United States. However, there are still utilities that have implemented optimal treatment but may still experience lead levels at or near the action level for lead, or those that would like to go a step further in reducing lead levels measured in their system by proactively replacing lead source materials. For these utilities, an understanding of the contributions that various lead based materials may have on lead levels measured at the tap would be useful. The stated goal of this Project was "to research and quantify the contribution of lead service lines, utility-owned in-line components, and customer-owned plumbing fixtures to Lead and Copper Rule compliance issues." The results of this Project also address the broader long-term goals of moving the industry towards a new 'lead free' future and providing information that can be directly applied to future regulatory reviews of the LCR.

The approach for this project was to complete a literature review and national survey of lead source characteristics and jurisdictional issues; conduct case, pilot, and field studies; and perform basic research on corrosion by-product scales found on lead based material. Results from these activities were used to expand the knowledge base on lead release from lead based materials in the system, and to develop guidelines for utilities in developing programs to reduce lead in drinking water.

The literature review summarized the following:

- Historical and current knowledge related to drinking water regulations for lead;
- Standards and controls on lead in materials used in potable water systems;
- How various sources of lead can potentially contribute to lead levels measured at the tap;
- The effectiveness of corrosion control treatment in reducing lead levels at the tap (in particular the effectiveness of phosphates as used in the United Kingdom); and
- Basic theory and understanding of the formation of scales on premise and distribution system materials.

The national survey generated a snapshot of typical industry service line jurisdiction issues and physical characteristics of service lines. Several utilities provided historical information documenting experiences with partial and full lead service line replacement, leaded meter replacements, implementation of no-lead component replacement programs, and the effectiveness of corrosion treatment using phosphate based inhibitors in reducing lead levels.

Two pilot evaluations were completed; a study of lead release from residential brass kitchen faucets and an evaluation of lead release from residential meters. In addition, results from a separate pilot study of excavated lead service piping were provided to the project team. Field sampling designed to estimate lead source contributions before, during, and after lead service or faucet replacement was conducted at several utilities. In a more fundamental research oriented effort, lead based materials were removed from the pilot and field study locations for assessment of scale material that had developed on the interior surfaces. The scale analyses were then used to correlate the elemental and mineralogical content of these interior scales to distributed water quality conditions, and develop hypotheses on their role in release of lead to the water.

FINDINGS AND CONCLUSIONS

What are the Sources of Lead Release

The sources of lead at the tap as measured in sequential samples (i.e. profile sampling where consecutive samples are collected at the tap after a minimum 6-hour standing time) include lead service lines, lead-based materials contained in the premise piping (leaded solder, brass/bronze fittings, galvanized piping), faucets, and water meters (See Figure ES.1 for a schematic of a typical premise piping configuration). Table ES.1 lists the average contribution from these lead sources, based on "mass of lead" results from this study.

Table ES.1
Average % Contribution of Major Lead Sources

Lead Source	Average % Contribution to Mass of Lead Measured at Tap during Profile Sampling (1)
Lead Service Lines	50% - 75%
Premise Piping	20% - 35%
Faucets	1% - 3%

(1) From sites with lead service lines. Based on "mass of lead" results measured at the tap from sequential samples collected for this study

Residential water meters contributed a relatively small mass of lead in comparison to the other lead sources, and mixing and dilution will likely minimize their contribution to lead levels measured at the tap.

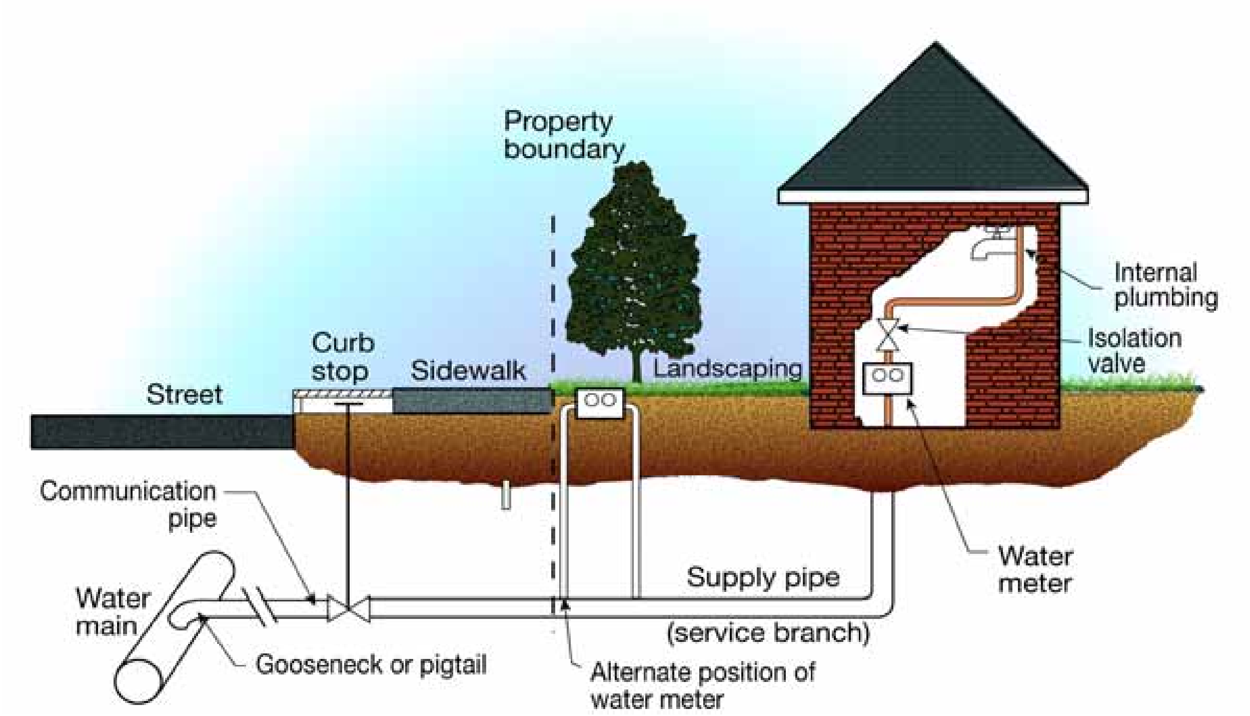

Figure ES.1 Typical premise plumbing configuration

What are the Factors that Contribute to Lead Release from Lead Sources in the System and Uptake by the Water?

Contributions from the various lead sources to samples collected at the tap, whether measured from sequential 'profile' samples, or from first liter 6-hour standing LCR compliance samples, will be influenced by a number of factors, including physical characteristics of the lead source (length, diameter, surface area), water quality conditions, water use and hydraulic patterns, and mixing and dilution effects as the water flowed during sampling.

In addition, it is hypothesized that the presence of a lead service line at an individual site may elevate the contribution of individual sources by providing an additional source of lead, either by 'seeding' the premise system with lead or introducing lead derived from the service at the start of the stagnation period. It is possible that over time, lead from the lead service 'seeds' the system by moving through and potentially being incorporated into the scales built up on the surfaces of the premise piping (including the faucet), from which it can be released over time depending on physical and chemical conditions. Lead can then be taken up into the water during stagnation and measured in standing samples collected at the tap, or picked up during flowing conditions. Therefore, when a lead service line is present, it is likely a significant and may be a controlling factor in the total amount of lead measured at that site, and the mass of lead contributed by individual lead sources.

Also, there is a great deal of variability in faucets, including differences in how faucets are constructed, the alloys used to make the various faucet component parts, and in the manufacturing processes themselves. These factors can affect the release of lead from new faucets and the intermittent release of lead over time as the faucets age, making it difficult to estimate 'typical' lead release under specific water quality conditions. In addition, non-leaded faucets may contain component parts that are made from alloys that contain lead, and may therefore be subject to lead release.

What is the Effect of Replacing Lead Sources on Lead Levels Measured at the Tap

Results from this study indicate that replacement of lead-based materials can reduce the total mass of lead as measured at the tap during sequential 'profile' sampling. The most effective way to reduce the total mass of lead measured at the tap is to replace the entire lead service line, followed by replacement of lead sources in the premise piping, the faucet, and then the meter. Removal of the entire lead service line appears to have two definitive benefits: removal of a direct source of lead released into the water and possible removal of a 'seeding' source of lead to downstream piping and appurtenances. Removing the lead service may lower the contribution of lead from other lead sources as this 'seeded' lead is 'flushed' from the system over time.

With respect to LCR compliance, removal of the entire lead service will reduce a direct source of lead that could be present at the beginning of the stagnation period which could contribute to lead measured in compliance samples. Lead service line removal may also lower the amount of lead the faucet and premise piping contribute to LCR compliance samples because it would remove a 'seeding' source of lead that may have been incorporated over time into the scales on the surface. In either case, it should improve LCR compliance over time.

Replacement of only a portion of the lead service ("partial lead service line replacement") did not result in improvements in first liter lead levels, and resulted in only minimal improvement in the total mass of lead measured at the tap in this study. Site specific factors will affect the amount of reduction that can be seen in full versus partial lead service line replacement. However, based on the results from this study, full lead service line replacement is preferable to partial replacement.

No improvement in either first liter standing lead levels or reductions in total mass of lead measured at the tap were seen with replacement of faucets in the time frames evaluated in this study. Inherent variability within and between faucets available for residential use makes it difficult to estimate lead release patterns and select appropriate replacement faucets. Therefore, replacement of faucets and end-use fittings may or may not improve lead levels at the tap; however, it may be appropriate at sites without lead service lines that may experience elevated lead levels in first draw samples. At these sites, the relative contributions of lead sources in the premise piping (lead solder, brass fittings, and faucets) may need to be distinguished. Field studies of meter replacement were not evaluated; however, the potential contribution of meters to first liter, standing lead levels was estimated to be quite small.

Are there Drawbacks to Replacing Lead Sources in the System?

For both partial and full lead service replacement, elevated lead levels may occur in standing samples in the short term (up to 3 days), and may in some cases, persist for longer periods of time, particularly if only a portion of the lead service is removed. How long these elevated lead levels will persist is likely to be site specific, dependent on the materials and water quality at each site and the amount of disturbance during replacement. Physical disturbance to the meter can also cause high, particulate lead release. Study results also indicate that the method used to cut the service line during replacement may affect the total mass of lead measured at the tap. Utilizing a coarse cutting method (such as a hacksaw) may cause more disturbance on the surface of the pipe than other, less damaging cutting methods (such as a disc cutter), and increase the lead levels measured at the tap after replacement.

What Lead Sources Have the Most Effect on LCR Compliance?

With respect to LCR compliance, most of the lead in the first liter, 6-hour standing LCR compliance sample will originate from lead sources in premise piping and the faucet. Results from this study indicate that the premise piping contributed an average of 84 percent of the lead in a first liter standing sample, and the faucet and immediate connective piping averaged 16 percent. However there was a wide range of percent contributions depending on individual site characteristics. For sites that do not contain a lead service line, lead released directly from the leaded solder and leaded alloys used in the manufacture of faucets and fittings will directly contribute to lead measured in LCR compliance samples. For sites that contain a lead service, it is hypothesized that lead derived from the lead service line may elevate the direct contribution of lead from the premise piping and the faucet by providing an additional source of lead, either by ‘seeding’ the premise system with lead or introducing lead derived from the service at the start of the stagnation period.

What Types of Scales Develop on Lead Source Materials and How Do These Scales Affect Release of Metals?

Results of basic research on the characterizations of scales from various utility and customer owned pipes and components indicated that for faucets and meters, scales may be chemically homogeneous and for faucets, the scale composition may be different between the cold water versus the hot water supply line. De-zincification appears to be the primary lead release mechanisms for brass materials, and brasses with higher zinc content may be more resistant to release of zinc, and hence lead. For lead and brass pipe, scales may be relatively homogeneous along the length of the pipe and contain several layers as well as various amounts of crystalline and amorphous compounds depending on the distributed water quality conditions at individual locations. Most scales on lead piping consisted of multiple layers with the surface-most layer being somewhat lower in total lead, but high in amorphous compounds of other elements such as iron and manganese. It is hypothesized that the structure and composition of this surface-most scale layer will likely have a strong influence on lead release. Changes in water quality, either seasonal or from treatment changes, could increase the solubility of the surface lead minerals or could also increase the solubility of the iron and manganese minerals, destabilizing the physical structure of the scale and releasing lead-rich particulates. These scale results were specific to the water quality and materials compositions at each specific site; however, they provide needed research on the formation and characteristics of scales that form on the interior of pipes, fittings, and components in drinking water systems, how these scales affect release of lead, and an understanding of models of lead release and uptake that result in lead measured at the tap.

What Regulations and Standards Exist for Lead Content in Plumbing Materials?

The original 1986 Safe Drinking Water Act (SDWA) required the use of ‘lead-free’ pipes, solder, pipe fittings or plumbing fixtures, where the term ‘lead-free’ was defined as pipe and brass components containing less than 8 percent lead and solder less than 0.2 percent lead. In 1996, the development and implementation of National Sanitation Foundation (NSF) Standard 61, Section 9 satisfied a requirement for the United States Environmental Protection Agency (USEPA) to set a performance standard that would establish lead leaching levels in fittings used for water intended for human consumption. As a result, plumbing fixtures and fittings that have a lead content of 8 percent or less and are NSF/ANSI Standard 61, Section 9 certified can be defined as “lead free” per the SDWA. The State of California has passed the Safe Drinking Water and Toxic Enforcement Act, commonly known as Proposition 65 (Prop 65) which required manufacturers to prove that ingredients in their products pose no significant risk of causing cancer or reproductive toxicity. Based on this Act, lawsuits have occurred that further refine the impacts of Prop 65 on suppliers of materials for potable water systems. Materials suppliers have now developed a number of alloys that are manufactured without the addition of lead and contain extremely low lead levels (<0.25 percent). Brass faucets, meters, and fittings made of these materials are now on the market.

How Can Utilities Decide Whether to Adjust Treatment or Replace Lead Sources to Comply with the LCR?

Corrosion control treatment to reduce the corrosivity of the water towards lead and copper materials is likely still the best and most cost-effective way to comply with the requirements of the LCR. In addition to LCR compliance, corrosion control treatment also reduces the mass of lead measured at the tap in sequential ‘profile’ samples, reducing public exposure to lead. Therefore, a re-evaluation of the current treatment approach should be the first step taken in an overall lead reduction strategy. Utilities that wish to implement a lead source replacement program will likely make the decision based on factors other than LCR compliance, such as a desire to be proactive with respect to removing lead sources from their system or to address site-specific issues related to high lead levels. Utilities will need to design lead reduction programs with their unique water quality, materials, and site characteristics in mind. However, common sense tells us that, in the end, lead source removal is the most certain route to eliminating lead in drinking water. If none of the materials in contact with the drinking water contain lead, then plumbosolvency becomes a moot issue. The authors of the legislation behind the LCR recognized this, but, at the same time, they recognized that wholesale replacement of all leaded materials in plumbing systems was not achievable at that time, both for technical and economic reasons. That legislation was passed 16 years ago, since then, a great deal of progress has been made. The water industry has learned a great deal more about methods of minimizing the release of lead from lead surfaces exposed to water, and it has made a great deal of progress in removing lead services. This report clearly demonstrates that the consumer’s portion of the lead service line remains an important unresolved source of lead. This issue is beyond the jurisdiction of local water utilities and other resources will be required if it is to be resolved. Once this issue is resolved, American homes will clearly be on a path toward lead-free drinking water.”

CHAPTER 1
STUDY CONCLUSIONS

PROJECT OBJECTIVES AND APPROACH

The objective of this research project was to evaluate the contribution of lead service lines and utility and customer-owned plumbing components to Lead and Copper Rule (LCR) compliance issues, and to develop guidance for the water supply community in developing lead mitigation strategies that will further protect public health.

This project utilized information from historical literature, conducted a national survey of lead source characteristics, completed case studies of lead source removal and corrosion treatment effectiveness, and completed field and pilot study activities designed to estimate the contributions of various lead sources to lead levels measured at the tap. This information was used to evaluate the relative contribution of various lead sources to lead levels at the tap and how these contributions might affect compliance with the LCR. In addition, an assessment of the impact of pipe cutting tools was completed to provide guidance on the best methods for removing lead service lines. The composition of scales built up on lead source materials was evaluated to expand the knowledge base related to identification of compounds that form on leaded materials in drinking water systems and correlations between these scales and distributed water quality conditions.

REPORT STRUCTURE

The extensive results obtained from the survey, case studies, pilot and field evaluations, and scale analyses are contained in a CDROM accompanying this report. This text report contains a synthesis of this information which was used to develop guidelines and criteria for utilities as they develop programs to further reduce lead in drinking water. The report contents are organized as follows:

- Chapter 1 – Study Conclusions
- Chapter 2 – Background Information and Research Summary
- Chapter 3 – Contributions of Lead Sources to Lead Levels at the Tap
- Chapter 4 – Lead Level Reduction Approaches and Decision Making Criteria

The accompanying CDROM can be accessed for more detailed information on the methods, materials, and results of the research, and contains the following appendices:

- Appendix A – National Survey of Lead Source Characteristics and Jurisdictional Issues
- Appendix B – Case Studies of Lead Source Replacement and Treatment
- Appendix C – Pilot Evaluations of Lead Source Contributions
- Appendix D – Metallurgical Analysis of Faucet Components from Portland Water Bureau Faucet Study
- Appendix E – Mineralogy Results of Brass Residential Water Meters
- Appendix F – Field Evaluations of Lead Source Contributions
- Appendix G – Scale Analysis Procedures for Piping Specimens
- Appendix H – District of Columbia Water and Sewer Authority Lead Profiles

STUDY CONCLUSIONS

Conclusions drawn from this study have been summarized below, categorized by major area of investigation.

Relative Lead Source Contributions

Contributions of major lead sources (lead service lines, premise materials, faucets) to lead levels measured at the tap (whether 1-liter first-draw samples for the LCR or more general samples) were evaluated using case studies, pilot evaluations and field data collection. Typical concentrations and mass of lead measured in samples representative of each major lead source were determined based on sequential sampling at the tap, and lead release from individual lead containing components (meters, faucets and lead pipe). Major conclusions from this portion of the project are summarized below.

- *Lead Service Lines.* Lead service lines were the major contributor to lead levels measured at the tap during sequential sampling, and were found to contribute an average of 50 to 75 percent of the total mass of lead measured at the tap.
- *Premise Piping.* Premise piping was a large contributor to lead levels measured at the tap during sequential sampling, but was generally less than the contribution from the lead service lines. Premise piping was found to contribute an average of 20 to 35 percent of the total lead mass measured at the tap.
- *Water Meters*. The contribution of a residential meter to total mass of lead measured at the tap during sequential sampling was relatively small when compared to the contributions of the premise piping and lead service lines. Depending on the location of the meter, mixing and dilution will minimize its contribution to lead levels measured at the tap.
- *Faucets and Immediate Connective Piping.* The contribution of the faucet to total mass of lead measured at the tap during sequential sampling was relatively small when compared to the contribution of the premise piping and the lead service lines. Faucets and immediate connective piping, as identified by the first 125-mL sample collected at the tap, were found to contribute from 1 to 3 percent of the total lead measured at the tap.
- *Multiple Sources and Factors.* Lead can be picked up as water flows through areas containing a lead source on the way to the tap. This could be due to erosion, scour, rapid solubilization of lead, and/or mixing. This uptake of lead by the water makes it difficult to characterize lead derived uniquely from specific sources, particularly those that are further away from the tap.
- *Flushed Samples.* The relative percent lead contribution from sequential samples representative of the distribution main averaged from 3 to 15 percent of the total mass measured at the tap. Lead contained in these samples was likely from uptake of lead as water flowed through the service line and premise plumbing system.
- *Impact of Lead Service Lines.* The amount of lead released from various lead sources in the system was larger at sites with lead service lines in place. Lead from the service line may migrate through the system and be incorporated into the scales built up on lead surfaces in the premise piping (“seeding”). This lead can potentially be re-

released over time depending on physical, hydraulic, and chemical conditions. This hypothesis needs to be confirmed in future studies.

- *Water Treatment.* Orthophosphate treatment was very successful at reducing lead levels at the tap from all lead sources reviewed as part of this project.

Impact of Replacing Lead Sources on Lead Levels at the Tap

An assessment of the effect of lead service line and faucet replacement on lead levels measured at the tap was completed using historical information and results of sequential sampling conducted at field study locations. A summary of conclusions are presented below.

- *High Particulate Lead.* Short-term, high-particulate lead levels often occur after both full and partial lead service line replacement because of disturbance of the existing service lines and/or premise plumbing caused by excavation, cutting, and replacement activities. This can occur in both stagnation samples and in fully flushed samples. A rigorous flushing regime (up to 60 minutes) may help reduce high-particulate lead levels measured in the days immediately following replacement.
- *Full Lead Service Line Replacement.* Full lead service line replacement reduced the total mass of lead measured at the tap during sequential sampling as well as the calculated first-liter lead level measured at the tap after 2 months, except in cases where lead levels were already low (~5 μg/L) prior to replacement.
- *Partial Lead Service Line Replacement.* For partial lead service line replacements, the total mass of lead and the calculated first-liter lead levels measured at the tap may not be different 2 months after replacement when compared to levels measured before replacement. In most cases, partial replacement of lead service lines was of very limited effectiveness in reducing lead levels measured at the tap in the time frames evaluated for this study.
- *Full Versus Partial Lead Service Line Replacement (LSLR).* “Full LSLR” is preferable to “partial LSLR”. While lead levels may eventually be reduced to below levels measured prior to replacement, experience from this study has been that at 2 months after replacement, no improvement in first-liter lead levels, and only minimal improvement in total mass of lead, was measured when partial lead service lines were removed. A longer period of time may be needed to realize improvement in lead levels at the tap after partial lead service line replacement.
- *Effect of Lead Service Line Replacement on Lead Contributions from Other Sources.* Removal of the full lead service line reduced the mass of lead in sequential samples representing the premise piping, faucet, and main after 2 months. It is hypothesized that over time, lead from the lead service line may ‘seed’ the system by moving through and being incorporated into the scales built up on internal surfaces in the premise piping. Removal of this ‘source’ of lead and continued water use may flush this lead from the system over time, reducing the contribution of the premise piping and faucet to lead levels at the tap.
- *Good Management Practices for Lead Service Line Replacement.* Full lead service line replacement should be a goal for reducing lead levels measured at the tap and complying with the LCR. Best management practices should be implemented during replacement of lead service lines however, in order to reduce customers’ exposure to lead. These include utilizing a pipe cutting method that will lessen the disturbance on

the surface of the pipe, incorporating flushing and additional monitoring to evaluate lead levels at the tap after replacement, and communicating to the public steps that can be taken to reduce their exposure to potentially high lead levels immediately following replacement.

- *Faucet Replacement.* Replacing existing faucets with non-lead alloy faucets may not have a significant impact on total mass of lead measured during sequential sampling at sites with lead service lines, or at sites with very low initial lead levels. However, replacement of faucets and end-use fittings may still be appropriate at sites without lead service lines that may experience elevated lead levels, and at buildings and schools that contain several end-use components that are dedicated primarily for drinking water. In any case, at locations where faucets are replaced, follow-up monitoring should take place to document the impact of replacement on tap lead levels. This is an area where further research is needed.

Potential Impact of Lead Sources on LCR Compliance

A discussion of the impact that various lead sources (faucet, premise, service piping) may have on LCR compliance are presented using information gathered from this study on lead source contributions and the impact of replacement.

- *Site Specific.* The impact of various lead sources (faucet, premise, lead service line) on LCR compliance will be site specific and should be evaluated on a case-by-case basis.
- *Premise Piping and Faucet Contributions.* Lead measured from the first 125-mL volume of water collected at the tap (i.e., the faucet and immediate connective piping) at lead service line sites and at sites where a full lead service line replacement was completed typically represented an average of 16 percent (range of 5 to 31 percent) of the lead to the first-liter sample at the tap. The remaining volume of water contained in the first liter (the second 875 mL) contributed an average of 84 percent of the lead in the first liter sample (range of 69 to 95 percent).
- *Factors Affecting Lead Release and LCR Compliance.* LCR compliance at a particular site will be dependent on the water use patterns prior to stagnation, the flow rate at the site, the surface area of lead exposed and the volume of water exposed, the amount of lead present in the scales and the characteristics of the scales, and water quality conditions.
- *Lead in Background Samples.* At sites with lead service lines, fully flushed samples may contain measurable lead due to uptake of lead as the water flows through the system to the tap. Therefore, measurable lead may be present in the background water at the start of the stagnation period for LCR sampling, further elevating lead levels after stagnation.
- *Affect of Lead Service Lines on Lead Contributions from Other Sources.* If a lead service line is in place and lead levels measured at the tap are relatively high, then lead derived from all sources (faucet, premise, service) may be elevated when compared to sites without a lead service line in place, possibly due to ‘seeding’ of lead from the lead service line. Removal of the service may reduce the contribution of lead from these sources and improve first liter lead levels.

- *Sites with Low Lead Levels.* If lead levels are initially low at sites with lead service lines, then removal of the service will likely not substantially improve the first-liter lead level and may cause increased lead levels in the short term. While eventual removal and replacement of all lead sources in the system should be the ultimate goal, the implementation of removal of publicly controlled sources such as lead service lines at utilities where corrosion control has been optimized (and hence compliance lead levels are low) may need to be managed carefully to minimize public exposure to elevated lead levels that may result due to the disturbance.

Faucets

Several conclusions related to faucets were drawn from this study based on historical data, case studies, field sampling, and a study of six commercially available residential brass kitchen faucets conducted at the Portland Water Bureau's Water Quality Laboratory, as described below.

- *Contribution to Total Mass.* In general, the mass of lead derived from faucets represented a small percentage of the total lead mass measured at the tap during sequential sampling at sites with lead service lines.
- *Contribution to First Liter Sample.* Faucets and immediate connective piping can typically contribute from 5 to 31 percent of the lead in the first liter sample collected at the tap for LCR compliance.
- *Faucet Variability.* There are widespread variabilities within and between faucets that are available for residential use, due to the variability in lead content of the alloys used to manufacture faucet parts, the physical configuration of the faucet, and manufacturing processes used to make the faucet. Therefore, duplicate faucets (same manufacturer and model) may exhibit very different lead release characteristics even when exposed to similar conditions.
- *Lead in Non-leaded Faucets.* Non-leaded faucets may contain parts exposed to water that are made of leaded brass alloys, and these parts may contribute to lead levels measured in the water.
- *Pilot Study Conclusions.* Several conclusions were drawn from the pilot study of faucets completed at the Portland Water Bureau. These are listed below:
    1. Lead release from faucets may increase over time and random high lead levels can be measured after long periods of use, likely due to physical disturbance of the existing scale and/or dezincification. These results would appear to contradict the idea that lead release from faucets would be greatest when they are new, and decrease with time.
    2. Sampling at higher flow rates (up to 4 L/min) may result in higher lead concentrations from faucets when compared to lower sample flow rates (1 L/min).
    3. Particles lodged in the faucet aerators may or may not contain lead. Results from the pilot study indicated that aerator particles did not contain lead, however this could be because either all lead being released was in dissolved form, the aerator captured lead particles but these particles subsequently dissolved and were flushed from the faucet, or the interstitial spacing in the aerator was too large to trap any released particles.

4. Faucets are comprised of multiple parts that may have different lead contents and lead release from faucets may originate from only one part of a faucet. Of the six brass residential kitchen faucets tested at the Portland Water Bureau, lead release was found to be localized to a specific 60 mL sub-volume within a given faucet.
5. Approximately half of the lead in a 6-hour stagnation sample may be released in the first 30 minutes of the stagnation period.
6. Non-leaded faucets may release low levels of selenium (0.6 μg/L or less).

Meters

Conclusions related to lead release from meters were drawn from this study based on historical data, case studies, and a study of six commercially available residential meters conducted at the Seattle Public Utilities Water Quality Laboratory. These are presented below:

- *Meter Contribution*. Meters contribute a small mass of lead that will eventually arrive at the tap, but dilution and mixing due to flowing conditions in the premise system will likely obscure the ability to detect the slug of lead.
- *Old Meters.* Older water meters can contribute lead to the drinking water at detectable levels, but significantly less than the action level of 15 μg/L. Older meters were found to be minor contributors to the overall lead exposure at Seattle Public Utilities due to the well-passivated surface that limited metal corrosion.
- *New Meters.* New leaded brass meters can release significant amounts of lead initially.
- *Non-leaded Meters.* Non-leaded meters can release very low, but detectable, levels of lead, bismuth, and selenium.
- *Affect of Flow Rate.* An increase in flow rate through the meters from 1 L/min to 4 L/min did not result in increased lead levels.
- *Affect of Physical Disturbance.* Physical disturbance to water meters, especially older meters, can have a significant negative impact on developed corrosion scales and release of lead.

Typical Lead Source Characteristics and Jurisdictional Issues

Results from a national survey were compared to information obtained in previous surveys and historical literature to develop typical service line characteristics and jurisdictional issues related to lead sources in the system. Major conclusions are listed below.

- The average total length of service lines (main to residence) reported was estimated to be 55 feet for older areas, and 68 feet for newer areas of the distribution system. The utility portion of the service averaged 25 feet in older areas and 27 feet in newer areas.
- The majority of survey respondents indicated that the water main was located near the curb, followed by off-set from the center of the street.
- Typical service line ownership extends from the main to the curb stop, and the vast majority of utilities also own the meter.
- Property owners are generally responsible for replacement of their portion of the service line.

- Specifications for installation of non-lead components are being implemented at several utilities, and some have programs to replace lead containing components in their system with non-leaded versions.

Scale Analyses

Conclusions related to the composition and characteristics of internal corrosion scales on excavated lead based materials evaluated for this study are presented below:

Faucets and Meters

- The primary lead release mechanism for new faucets and meters was dezincification, as evidenced by the formation of a porous zinc-depleted layer on the internal surfaces through which lead could diffuse or lead particulates could be detached.
- The extent of scale coverage increases with increasing age of components and the rate of dezincification may be inversely related to the amount of zinc in the material.
- Higher zinc brasses, as evaluated in the meter study at the Seattle Public Utilities, appeared to be more resistant to release of zinc, and hence lead.
- Scale was chemically homogeneous and the composition can be different from the cold water versus the hot water supply line.

Lead and Brass Pipe

- It is hypothesized that the presence of high iron and manganese in the water may cause releases of particulate lead from lead service lines as lead sorbed to iron and manganese scales on the pipe wall is released. Further work is needed to confirm or refute this hypothesis.
- Lead compounds typical for the distributed water quality conditions at individual locations were identified. For example, at locations where phosphate was used as a corrosion inhibitor, the lead phosphate pyromorphite was identified.
- Scales were relatively homogeneous along the length of the pipe or fitting, but for lead pipes, consisted of several distinct layers. These layers were generally litharge (PbO) at the pipe wall, then one of the lead carbonates, then a complex surface scale with non-lead compounds of iron, manganese, calcium, or aluminum, plus plattnerite or pyromorphite depending on the utility.
- The composition of the surface scale layer impacts lead release, with more lead released, possibly as particulates, from surface scale layers that contained more non-lead elements.
- Thicker scale development occurred at the lead service line/brass connection interface.
- Brass pipe scales were dominated by copper minerals, or in one case, manganese oxides.

CHAPTER 2
BACKGROUND INFORMATION AND RESEARCH SUMMARY

INTRODUCTION

This chapter presents a variety of background information related to lead in drinking water, including 1) regulations, standards, and legal mechanisms in place for control of lead in drinking water and lead in materials used in potable water systems; 2) the various sources of lead and how they can potentially contribute to lead levels measured at the tap; 3) the effectiveness of corrosion control treatment in reducing lead levels at the tap from both a US and UK perspective; and 4) basic theory and understanding of the formation of scales on premise and distribution materials, including the solubility of those scales, and how their chemistry affects lead levels measured in water. The goal of presenting this information is to provide the reader and practitioner with sufficient understanding of the history and inter-related chemical, physical, material, and legal factors involved in controlling lead in drinking water.

In addition, this project collected a great deal of data and information related to utility experiences with leaded materials, lead source contributions, affects of water quality on metals release from leaded materials, and scale characteristics of excavated leaded sources. Detailed discussions of these evaluations can be found on the CDROM accompanying this report, and a summary of these results are presented in this chapter.

BACKGROUND

History and Background on Lead Control in Drinking Water and Plumbing Materials

Overview

The 1986 SDWA required the use of “lead-free” pipes, solders, pipe fittings or plumbing fixtures used in the installation or repair of any public water system or any plumbing in residential or non-residential facilities supplying water for human consumption. Plumbing fittings and fixtures were not formally addressed in the 1986 Amendment and were required to meet “voluntary standards.” The term “lead-free” was defined as pipe and brass components containing less than 8 percent lead and solder less than 0.2 percent lead. The 1986 SDWA also called upon the USEPA to develop a testing procedure to regulate the concentration of lead in the water at the consumer’s tap.

The 1988 SDWA Amendments included the Lead Contamination Control Act (LCCA) and were focused on lead contamination of school drinking water supplies. The LCCA required USEPA to publish a guidance document on how to evaluate lead contamination in these supplies. The LCCA also required that USEPA identify drinking water cooler brands with lead and non-lead liners on drinking water coolers and that all lead-lined coolers be replaced. The USEPA responded to this in 1989 with a recommended tap-sampling procedure that limited the concentration of lead to 20 ppb in a 250-mL sample, collected after overnight stagnation in the building piping. This was provided as guidance to school districts and was not mandated.

In 1991, the USEPA finalized the LCR in response to the 1986 SDWA, and this rule regulated lead contamination at the consumer’s internal tap. The testing procedure specified in the rule involved sampling the first 1 liter from the consumers tap after the water remained in the pipe overnight (minimum of 6 hours) and measuring the lead concentration. Utility action was triggered when the fraction of the samples with more than 0.015 mg/L of lead was found to be greater than 10 percent (action level). A more detailed description of the LCR can be found later in this section.

The 1996 SDWA Amendments (1996 SDWA) finalized the current federal legislation on lead in the public water supply. The 1996 SDWA expanded legislation to include plumbing fittings and fixtures and required that the USEPA issue regulations setting a performance standard that would establish lead release levels in fittings used for water intended for human consumption within 2 years if voluntary standards were not implemented by the industry within the first year. The term "lead free" for plumbing fittings and fixtures would be re-defined by this performance standard. In 1997, the USEPA declared that NSF 61, Section 9 satisfied the 1996 SDWA requirement that a voluntary standard be established and that USEPA was not required to issue regulations. As a result, endpoint devices (plumbing fixtures and fittings) that are NSF 61, Section 9 certified are "lead free" by definition. Section 8 of NSF 61 is used to certify that in-line devices are "lead free" while Section 9 is used for endpoint devices. Inline devices include valves, meters, backflow prevention devices, pressure regulators, and connection devices such as fittings, couplings, meter setters, corporation stops, and curb stops, whereas endpoint devices include faucets, hot and cold water dispensers, drinking fountains, bubblers and water coolers, and refrigerator ice makers. Plumbing products are generally regulated at the state or local level through plumbing codes which are based on Model Plumbing Codes such as the Uniform Plumbing Code (UPC), the National Standard Plumbing Code (NSPC), and standards by the American Water Works Association (AWWA), and the American Society of Mechanical Engineers (ASME), and American Society for Testing and Materials (ASTM). The UPC, International Plumbing Code (IPC) and NSPC all reference NSF/ANSI Standard 61 for pipe, fittings, and faucets but do not reference NSF/ANSI Standard 61 for in-line valves (AwwaRF 2007). Since individual states, counties, and cities determine the implementation of the plumbing code for their jurisdiction, there can be variation in requirements and enforcement.

The 1996 SDWA made it unlawful for any person to introduce into commerce leaded plumbing components, except for pipe that is used only for manufacturing or industrial processing. The 1996 SDWA provided a 2-year grace period for manufacturers of leaded components and by August 1998 manufacturers were required to comply. The following sections present summaries of the Federal LCR, NSF Standard 61, and Proposition 65, the state of California's legislation which impacts materials used in potable water systems.

The Lead and Copper Rule

The USEPA's 1991 LCR established maximum contaminant level goals (MCLG) and action levels for lead in US potable waters (USEPA 1991a). The MCLG for lead is zero while the action level (AL) is 0.015 mg/L measured in the 90th percentile of the samples. The MCLG for copper is 1.3 mg/L while the AL is 1.3 mg/L measured in the 90th percentile of the samples. The 1991 LCR also established sampling and monitoring procedures that US water systems are required to follow. Subsequently, the USEPA made minor revisions and rule clarifications to these sampling and monitoring requirements (USEPA 2000), and in 2007, published additional revisions related to sample collection, treatment changes, customer awareness, and lead service line removal programs.

Sampling and Monitoring Requirements. *Lead sampling*. The number of lead sampling sites that must be analyzed to comply with the LCR varies by the size of the population served by the water system. Under standard monitoring procedures, samples must be taken twice every 6 months from consumers' cold water kitchen taps after the water in the plumbing has experienced a stagnation period of 6 hours minimum. However, a water system can apply for a reduced number of monitoring sites and a lower sampling frequency if it maintains very low levels of lead or meets stringent water quality specifications. The standard and reduced numbers of sampling sites are listed in Table 2.1. The requirements for reduced monitoring are listed in Table 2.2.

Sample collection and monitoring must occur at sites that have a high risk of lead levels in the drinking water. To ensure this would happen, sites are assigned priorities for usage depending on their characteristics (see Table 2.3). If there are not enough residences in the Tiers to meet the sampling site requirements, the balance of the sampling sites will be at residences that have plumbing that is representative of the system.

Table 2.1
Required sampling sites for lead and copper monitoring

	Required number of sampling sites	
Population served	**Standard**	**Reduced**
>100,000	100	50
50,001 – 100,000	60	30
10,001 – 50,000	60	30
3,301 – 10,000	40	20
501 – 3,300	20	10
101 – 500	10	5
≤100	5	5

Source: USEPA 1991a

Water quality parameters. In addition to monitoring for lead, water systems may also be required to monitor the following water constituents and characteristics at every entry point into the distribution system and at the high-risk sites within the distribution system:

- pH
- Alkalinity
- Calcium
- Conductivity (initial monitoring only)
- Temperature (initial monitoring only)
- Orthophosphate or silica (only if such corrosion inhibitors are used).

Table 2.2
Requirements for reduced lead monitoring

Reduced sampling frequency	Water system requirements for reduced sampling frequency and sites
Annual	A system of any size that meets Optimal Water Quality Parameter (OWQP) specifications for 2 consecutive 6-month monitoring periods, or Serves ≤ 50,000 and measured lead and copper are less than their respective action levels for 2 consecutive 6-month monitoring periods.
Triennially	A system of any size that meets OWQP specifications for 3 consecutive years of monitoring, or a system of any size that has 90th percentile lead levels ≤ 0.005 mg/L and 90th percentile copper levels ≤ 0.65 mg/L for 2 consecutive 6-month periods, or a system of any that size that can demonstrate that the difference between the 90th percentile lead level at the sample tap and the highest lead concentration in its source water is ≤0.005 mg/L for 2 consecutive 6-month periods, or Serves ≤ 50,000 and measured lead and copper are less than their respective action levels for 3 consecutive years of monitoring.
Once every nine years	Serves ≤ 3,300, has 90th percentile lead levels ≤ 0.005 mg/L, and the system is free of lead lines, pipes, and soldered pipe joints; leaded brass or bronze alloy fixtures; and plastic lines and pipes containing lead.

Notes: OWQP are specific ranges or minimums determined by states for each water quality parameter.
Source: USEPA 1991a, USEPA 2000

Table 2.3
Lead and Copper Rule compliance monitoring site tiers

Tier	Description	Note
1	Single-family residential houses with a lead service line or with lead-soldered plumbing that was installed after 1982.	Water system must collect samples from this tier.
2	Multi-family residences or other types of building with the same plumbing characteristics as Tier 1 houses.	Tier 2 residences are used only if a water system does not have enough Tier 1 residences to meet the required number of sampling sites.
3	Single-family residences with lead-soldered copper plumbing installed before 1983.	Tier 3 residences can only be used if a water system does not have enough Tier 1 or 2 residences to meet the required number of sampling sites.

Source: USEPA 1991a, USEPA 2000

The number of sampling sites required for monitoring these water quality parameters is shown in Table 2.4. The standard sampling frequency is twice every 6 months for water systems with service populations >50,000 people and for smaller systems with lead levels at the sample taps that exceed the action level.

Treatment Techniques. All systems serving >50,000 people are required to install optimal corrosion control treatment. The only exceptions are 1) those systems that have completed treatment steps prior to December 7, 1992 that are equivalent to those described in the 1991 LCR; and 2) those systems that can demonstrate that the difference between the 90th percentile lead level at the sample tap and the highest lead concentration in its source water is ≤ 0.005 mg/L for two consecutive 6-month periods. Water systems with service populations ≤ 50,000 are required to implement corrosion control treatment if lead or copper levels exceed the action level.

Table 2.4
Required sampling sites for lead and copper rule water quality parameters

	Required number of sampling sites[1,2]	
Population served	**Standard**	**Reduced**
>100,000	25	10
50,001 – 100,000	10	7
10,001 – 50,000	10	7
3,301 – 10,000	3	3
501 – 3,300	2	2
101 – 500	1	1
<100	1	1

Notes:
[1] Sampling is required only for systems serving >50,000 people or systems serving <50,000 people that have lead and/or copper levels in excess of the AL.
[2] Number of sites for standard and reduced monitoring is in addition to every entry point to the distribution system.
Source: USEPA 1991a, USEPA 2000

Systems exceeding the action level have 24 months to install a state-designated corrosion control treatment process. After installation, the water system must conduct two consecutive 6-month periods of follow-up monitoring. The state will set the OWQPs for the following parameters after these monitoring periods are completed:

- pH
- Alkalinity
- Calcium (if carbonate stabilization is used)
- Orthophosphate (if a phosphate-containing inhibitor is used)
- Silica (if a silica-containing inhibitor is used).

OWQPs represent the conditions which water systems must maintain in the distribution system in order to most effectively minimize lead levels at users' taps. Systems operating their treatment processes within their respective OWQPs are considered to be "optimized" with respect to distribution system corrosion control.

In addition, these systems must also sample the source water(s) and make a recommendation as to whether or not lead treatment is required. If the state requires, source water treatment, in addition to the corrosion control treatment, must be installed within 24 months of the action level exceedence. Systems with service populations ≤ 50,000 can stop the source water treatment if both lead and copper levels are below their respective action levels for two consecutive 6-month monitoring periods.

For utilities that previously met the action levels for the LCR, but exceeded them in future monitoring rounds, within 12 months after the end of the monitoring period during which the action level was exceeded, the State may require them to perform corrosion control studies. If no study is required, the State must specify optimal corrosion control treatment within 18 months for large and medium systems, and within 24 months for small systems. If a corrosion control study is required, systems must complete the study within 18 months from the time the state required the study, and the State must designate optimal corrosion control treatment (OCCT) within 6 months after completion of the study. Optimal corrosion control treatment must be installed within 24 months after the State designates OCCT, with follow-up sampling within 36 months. The State must designate optimal water quality control parameters within 6 months after follow-up sampling is completed and the system must operate in compliance with the State-designated optimal water quality control parameters and continue to conduct tap sampling as required.

Lead Service Line Replacement. Lead service line replacement is required if the system has LSL and continues to have lead levels in excess of the action level after a corrosion control and/or a source water treatment process has been installed. The USEPA-required schedule for lead service line replacement is 7 percent of lead service lines per year, although individual states can require an accelerated schedule. Lead service line replacement can be discontinued once the lead levels at the taps are below the action level for two consecutive 6-month monitoring periods.

There are two types of lead service line replacements, partial and full. A water system can monitor the lead levels in the lead service line to determine if it requires replacement. If lead levels are ≤ 0.015 mg/L, then the lead service line does not require replacement and counts as a replaced line. A lead service line replacement will be required if the lead service line lead levels are >0.015 mg/L.

Monitoring can stop once a full lead service line replacement is conducted. For a partial lead service line replacement, a water sample representative of the water in the remaining portion of the lead service line needs to be collected 72 hours after the replacement. The results of this sample must be mailed to the building owner and residents (if different) within 3 days of receipt of the results by the water system.

2007 Revisions to the LCR. The EPA reviewed the implementation of the LCR, to determine if additional guidance or changes to the regulation might be needed. In March, 2005, they announced a “Drinking Water Lead Reduction Plan’ to clarify specific areas of the rule and associated guidance materials. There were four specific areas of the LCR that were reviewed and included in a final rule published October 10, 2007 (USEPA 2007a). First, the revisions clarified sample collection procedures relating to the number of samples that should be collected and the number of sites that should be sampled. Secondly, it required utilities to gain approval from their primacy agency for any changes in treatment or source water that could increase corrosion of lead. Thirdly, utilities were required to provide lead level monitoring results to homeowners, and finally, the revisions added a requirement that previously “tested-out” lead service lines must be reconsidered if a utility is re-triggered into lead service line replacement.

NSF/ANSI International Standard 61

In response to a competitive request for proposals from the USEPA, a Consortium led by the NSF, agreed to develop voluntary third-party consensus standards and a certification program for all direct and indirect drinking water additives. The Consortium consisted of AwwaRF, the Association of State Drinking Water Administrators, the Conference of State Health and Environmental Managers, and AWWA. The NSF/ANSI 61 standard (Drinking water system components – Health effects) was developed through this process. This standard establishes minimum requirements for the control of potentially adverse human health effects from products that contact drinking water, and is intended for voluntary use by certifying organizations, utilities, regulatory agencies, and/or manufacturers as a basis of providing assurances that adequate health protection exists for covered products.

NSF/ANSI Standard 61, Section 9 relates to the amount of lead leached from a product. The standard dos not specify the lead content in the product. Certification by NSF/ANSI 61 Section 9 is granted if components release less than 11 μg/L in the first liter of water drawn under the conditions of the test specified in the standard (Q statistic). Section 8 describes a different testing protocol for in-line devices and requires the materials release less than 15 μg/L. Revision to NSF/ANSI 61 Section 9 were completed in 2007 (NSF 2007) which will effectively increase the public health protection of the standard by reducing the Q statistic from 11 μg/L to 5 μg/L. This change will take effect in July 2012.

Proposition 65

In November 1986, the State of California passed the Safe Drinking Water and Toxic Enforcement Act, commonly known as Proposition 65 (Prop 65). By definition, Prop 65 requires manufacturers to prove that ingredients in their products pose no significant risk of causing cancer or reproductive toxicity. If not, manufacturers are required to include a warning label on any product containing an ingredient “known to the state” to cause cancer or reproductive toxicity. Based upon this Act, lawsuits have occurred that are further refining the impacts of Prop 65 on the material suppliers to public water systems and some public water agencies.

The first Prop 65 court case revealed the need for a new test to define “no lead” components and prove that materials posed no significant health risk from lead according to Prop 65 legislation. “No-lead” defined components are permitted to be sold without being tagged in accordance with Prop 65. The test that was developed is based on NSF 61 Sections 8 and 9 using a “representative” water for California. As a result of this first Prop 65 settlement, manufacturers are required to tag plumbing and service components that release more than 0.5 μg/d for each person using water that comes through them. It is assumed that an average person consumes 2 L/d, resulting in a maximum concentration of 0.25 μg/L, much lower than the 11 μg/L allowed by the SDWA through NSF 61. These increased restrictions on lead release are creating a market of “no-lead” components that are capable of meeting these much stricter standards for lead.

Government agencies are officially exempt from Prop 65 lawsuits. However, the legal distinction between government, public, and private agencies seems vague because lawsuit cases have been expanded to include some public agencies (Los Angeles Department of Water and Power, San Francisco Public Utility Commission, East Bay Municipal Utility District, etc.). As a result of pressure from Prop 65, some public agencies have begun to adopt a “no-lead” program. These agencies are replacing “lead-free” (8 percent lead or less) components (particularly water meters) with “no-lead” components as a preventative measure. Some agencies also offer rebates to the public to encourage “no-lead” faucets and fixtures be purchased to replace current “lead-free” parts. As a result of Prop 65 settlements, monies have been made available to support these programs and the increased costs associated with “no-lead” components, compared to “lead-free” components, are paid for with some of these monies.

The impact of Prop 65 on California plumbing suppliers has been lawsuits and settlements. The settlements resulting from Prop 65 are encouraging the development of “no-lead” components and manufacturers that do not produce “no-lead” alternatives are incurring fines for the distribution of “lead-free” components for public water supplies in California. As time progresses, the penalties that manufacturers incur for distributing “lead-free” components are increasing and the sale of some “lead-free” components has been defined as illegal when the manufacturer has successfully developed “no-lead” components as defined in specific settlements. These penalties for the sale of “lead-free” components and the funds made available to encourage the development of “no-lead” components are changing the available market for those involved with maintaining or establishing public water systems.

No Lead Brass

The original 1986 SDWA specification, limiting the lead content in brass to 8 percent had little or essentially no impact on the lead content of brass fittings as the two most common alloys used for these fittings (ASTM 36600 and ASTM 34400) contain 7 percent and 5 percent lead respectively. The implementation of Standard 61 and Prop 65 suits have had a major impact on the lead in brass fittings. Materials suppliers have now developed a number of alloys that are either completely devoid of lead or contain extremely low lead levels (< 0.25 percent) and brass faucets, meters and fittings made of these materials are now on the market (e.g. Envirobrass and Federalloy).

Lead Sources in Distribution and Premise Piping

Primary sources of lead that can contribute to lead levels measured at the tap include:

- Lead service lines and leaded goosenecks (pigtails)
- In-line components (i.e. meters, valves, fittings) made of brass or bronze
- Internal (premise) piping, which includes lead solder used to join copper pipes, galvanized piping, and faucets and fittings made from brass or bronze.

Figure 2.1 displays a schematic of a typical residence, with these potential lead sources shown. Background on each of these primary lead sources is presented in the following sections.

Lead Service Lines

The typical service line consists of a service pipe extending from the water main to the building, with the length from the main to the curb stop or property boundary usually owned by the utility, and the length from the curb stop or property boundary to the building owned by the property owner (see Figure 2.1). Historical surveys have indicated that the typical total length of service lines is approximately 60 – 67 ft (18.3 – 20.4 m) with a utility jurisdiction of 20 - 27 ft (6 – 8.2 m) (Roy F Weston and EES 1990; AwwaRF 1994), however the range of lengths can vary depending on whether the service is located in an urban or suburban area. Urban locations will generally have shorter service line lengths and suburban areas will have longer lengths.

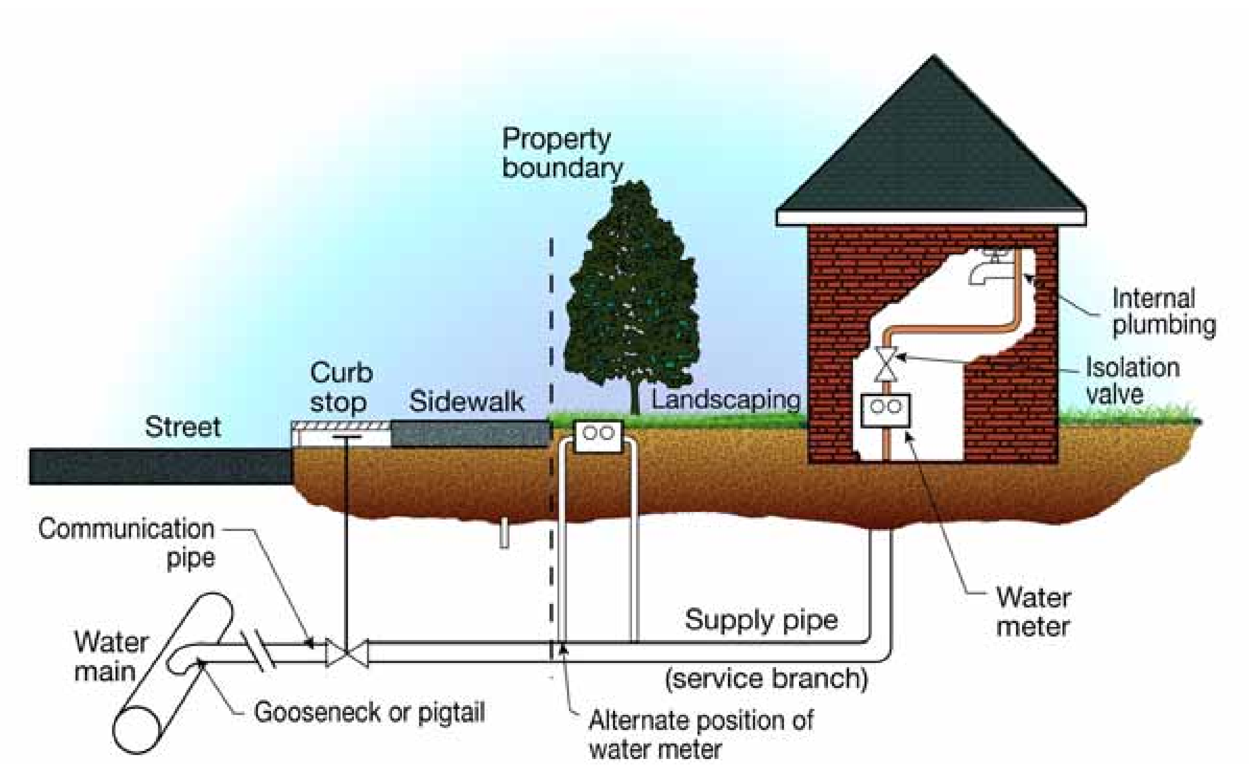

Figure 2.1 Typical premise plumbing configuration

Lead service lines have been shown to be significant contributors to lead in water (Schock 1989; Schock 1990; USEPA 1991a). The length and diameter of the lead service line is one factor that can affect lead levels measured at the tap, in addition to corrosivity of the water, other sources of lead in the system, and other site specific water use and hydraulic patterns. Longer lengths may result in higher lead levels, and smaller diameter service lines have a greater ratio of pipe surface to water volume which can result in higher lead levels. Replacing lead service lines will remove what could be a potentially large contributor to lead levels measured at the tap. Mechanical disturbances due to partial replacement of lead piping have been shown to elevate lead levels (Britton and Richards 1981; Breach et al. 1991; Hulsmann 1990; AwwaRF 1990; Wysock et al. 1991; Wysock et al. 1995; Boyd et al. 2004). These studies indicate that elevated lead levels and/or intermittent high lead level spikes may occur in water at the tap for a period of time following a partial replacement, and that it may take from several days to several months for lead levels to stabilize in lead piping that has been disturbed. Typical open trenching and cutting methods used to replace service piping can cause this disruption by vibrating or striking the pipe.

There has been little published field verification of the level and extent of elevated lead concentrations at the tap following partial lead service line replacement. Studies at the Greater

Cincinnati Water Works have shed some light on the effects of partial lead service line as experienced at residences in their system (DeMarco 2004; USEPA 2004). In one of these studies, very high lead was found following a partial replacement with subsequent sampling after 9 months finding the lead levels back down. Many times, flushing of the plumbing system decreased the lead levels. Lead spikes were measured in another Cincinnati study after partial lead service line changeovers. The spikes in lead concentration typically lasted between 1 to 4 weeks. But even after 1 year of sampling, no clear benefit was seen to partial line replacements over keeping the complete line in place.

In-Line Components

In-line components include mechanical devices such as valves, meters, backflow prevention devices, pressure regulators, and pump components, and connection devices such as fittings, couplings, meter setters, corporation stops, and curb stops that are used in the transmission and distribution of drinking water. These components, or their parts, are generally manufactured using some type of copper alloy material that contains lead as an alloying element. Copper alloys (brass and bronze) are typically used for in-line components. Brasses are alloys of copper and zinc, with the percentage of zinc generally ranging from 5 to 40 percent. As described previously, there are also in-line components available that are made using alloys with no lead added, i.e. that contain less than .25 percent lead. Typical leaded brass used in the manufacture on in-line components contain between 1.5 and 8 percent lead.

The capacity for typical brass alloys to release lead has been historically established (Samuels and Meranger 1984; Neff et al. 1987; Schock and Neff 1988; Gardels and Sorg 1989; Paige and Covino 1992; Lytle and Schock 1996; Kimbrough 2001). Lytle and Schock (1996) cited studies by Nielson (1975 and 1983) where lead released into water from water meters and meter fittings composed of brass, and main and stop valves composed of gunmetal, a copper alloy containing 5 percent lead. They also cited results from Birden, et al. (1985) where lead released from a copper pipe loop system that used no lead parts other than brass compression fittings.

Several internal studies of lead release from in-line components have been completed by the Environmental Quality Institute (EQI) at the University of North Carolina, Asheville (Maas et al.. 1997; Maas and Patch 1999). These studies evaluated metals release from a variety of water meters, valves, meters stops, couplings, meter setters, and elbows using an exposure water of pH 8.0, alkalinity of 100 mg/L as $CaCO_3$, and a chlorine residual of 1 mg/L. The procedure used to evaluate lead release was similar to NSF Standard 61, Section 9 (NSF 2001), with the exception that the parts were plumbed into a pressurized PVC manifold rather that filled and dumped. The volumes of water held in these components ranged from 6.5 mL for a compression elbow fitting to almost 680 mL for an angle meter valve. Results indicated that lead did release from these components under the testing protocol used, and that component parts made from higher lead content alloys released higher lead levels than component parts made from lower lead content alloys. Lead levels declined to approximately one half of initial levels after several weeks, and stabilized after 5 months.

The majority of metals release research for alloys that are used to manufacture in-line components has focused on dezincification, the preferential removal of zinc from the alloy (AwwaRF and DVGW 1996). The higher the zinc content of the alloy, the greater the potential for dezincification. Researchers have theorized that dezincification of zinc-containing alloys may result in more surface area of lead exposed to water, and therefore increase the potential for lead dissolution (USEPA 1993).

There is little peer-reviewed research addressing metals release from actual in-line components installed in drinking water systems, or the contribution that these components may make towards 1-liter standing samples collected at the tap as per the LCR. While in-line components may release lead into the water that will eventually arrive at the tap, the small amount of lead released, and the longitudinal dispersion which occurs as the water flows in the pipe, normally make it difficult to identify this source in the water that arrives at the tap, unless there are no other sources of lead.

Premise Piping

Premise piping and plumbing fixtures in residences and buildings typically consist of interior piping (usually copper or galvanized pipe), the solder used to join that piping, and faucets and fittings used to dispense water to the customer. Prior to the promulgation of the LCR in 1991, lead solder and flux used to join copper premise piping, and faucets and fittings comprised of brass were shown to be major sources of lead in tap water (Samuels and Meranger 1984; Schock and Neff 1988; Gardels and Sorg 1989; AwwaRF 1990; USEPA 1991a). To control these sources, solder and flux made of lead containing more than 0.2 percent lead were banned by the 1986 amendments to the SDWA. In addition, the LCR required that faucets and 'fixtures' be "lead free", which was defined as containing not more than 8 percent lead. Beginning with the 1996 amendment, in addition to containing no more than 8 percent lead, they are required to meet a standard for lead free plumbing, fittings and fixtures established in Section 9 of NSF Standard 61 (Federal Register Notice 1997; NSF 2001). Therefore interior faucets and fixtures must meet both the 8 percent lead content requirement as well as the leachability standards established by NSF 61, Section 9 to be considered 'lead free'.

Galvanized pipe is zinc coated steel pipe that may contain up to 1.4 percent lead, although the piping commonly used in the US has a lead content of 0.10 percent or less (AwwaRF 1989). Although galvanized pipe has generally been replaced with copper or PVC for use in home plumbing, it could be a source of lead at locations where it is still in use. The brasses most commonly used for household faucets and fittings include red, semi-red, and yellow brasses that contain about 1.5 to 7.5 percent lead (AwwaRF 1990, Lytle and Schock 1996). Kimbrough (2001) cited a source (Lovell et al. 1978) that found most brasses used in fixtures were made using yellow brass with either 30 or 40 percent zinc content. Faucets made from these alloys may still contribute to lead levels measured at the tap as per the LCR.

Lead release from leaded solder is highest with new (fresh) solder, but will decline over time (Oliphant 1983; USEPA 1991a). The contribution of lead soldered joints to lead levels at the tap is dependent on the number of joints, the age of the solder, the workmanship of the soldering, the volume of water exposed to the soldered joints, stagnation time, and water quality conditions. However, with the ban on use of leaded solder, the remaining major sources of lead in premise plumbing systems are likely fittings and faucets that can contain up to 8 percent lead. Lead release from galvanized pipe has also been documented (Seattle Water Quality Metals Committee 1974; Kennedy Engineers 1976).

With respect to faucets and fixtures, studies have shown that lead is released both from different copper based alloys typically used to make faucets (Lytle and Schock 1996) and from commercially available faucets evaluated in pipe rig and field settings (Neff et al 1987; Paige and Covino 1992; Schock and Neff 1988; Gardels and Sorg 1989). Lytle and Schock (1996) evaluated metals release from six different brass coupons under different water quality conditions. The highest lead levels released from these brass coupons occurred during the first 2 weeks of exposure to the water. Generally, the alloys with higher lead content released more lead. At pH 8.5, the lead concentrations stabilized after 60 to 70 days and at pH 7.0, the lead levels were still decreasing slightly at the end of the test run (155 days). Orthophosphate reduced the time required for lead levels to stabilize and a higher orthophosphate dosage (3 mg/L as PO_4) caused lead levels to drop and stabilize more rapidly than lower dosages (0.5 mg/L as PO_4). Gardels and Sorg (1989) mounted twelve different faucets upright to a manifold system and conducted metals release tests using distilled water and Cincinnati tap water. The higher lead levels were from faucets made with all cast brass interiors that were exposed to the more corrosive distilled water.

The Portland Water Bureau, as part of their corrosion control testing program, incorporated brass blocks into the pilot-scale testing apparatus. A cast red brass block (4-inch x 4-inch x 24-inch with six ¾ –inch ID holes drilled lengthwise) was utilized that contained approximately 3 percent lead, to represent materials typically used in home faucets and fittings. Lead levels were measured from the brass block after an 8-hour stagnation period under various water quality conditions. After stabilization, the range of lead release from the brass blocks was between 4 and 34 μg/L depending on the water quality being tested (Montgomery Watson and EES 1994). The lead results from the brass block were statistically similar to tap lead levels measured for regulatory compliance (AwwaRF 2004).

The contribution of the faucet to lead levels measured at the tap per the LCR will depend on the lead content of the brass, the volume of water in contact with the faucet, the physical configuration of the faucet and how it was manufactured, the quality of the water it is exposed to, and flow conditions. The volume of water in contact with the faucet will vary depending on the faucet model. Gardels and Sorg (1989) found that the volume of water exposed to the typical kitchen faucets they evaluated ranged from 56 mL to 135 mL. They suggest that samples no larger than 100 – 125 mL be collected when evaluating the amount of lead release from a household faucet. Gardels and Sorg (1989) estimated that as much as 75 percent of the lead released from common kitchen faucets was collected in the first 125 mL of water collected from the faucet. More than 95 percent of the lead released was in the first 200 to 250 mLs of water from the faucet. Based on monitoring surveys conducted by the American Water Works Service Company, it was estimated that brass faucet fixtures contributed 33 percent of the lead in first-draw, 1-liter samples collected at the tap (AWWSCo 1989). The Portland Water Bureau replaced kitchen faucets in 17 homes with non-metallic faucets to evaluate the effect that faucet replacement could have on lead levels in standing tap samples. Reductions in lead levels at the tap were greater than 30 percent in over half the homes (EES 1995).

Corrosion Treatment Techniques and Effectiveness

Lead in treated drinking water is extremely rare. Lead measured at consumers’ taps is primarily the result of corrosion of lead containing materials used in drinking water transmission, distribution, and premise piping systems. Corrosion treatment techniques have been applied by water utilities to reduce the corrosivity of their water to these materials and therefore reduce lead levels at the tap. One of the goals of this project was to develop criteria and guidance to assist utilities in making decisions about the effectiveness of lead source replacement versus corrosion treatment. In order to meet this goal, current understanding of the effectiveness of corrosion treatments was evaluated. The following section summarizes the implementation and effectiveness of corrosion treatment techniques used in the United States, and provides a more detailed examination of the status of corrosion treatment approaches and effectiveness in the United Kingdom, where there is extensive use of phosphate inhibitor chemicals.

United States Experience

The LCR and its associated guidance manuals established a process utilities could use to evaluate corrosion treatment alternatives. For large utilities (serving more than 50,000), this involved completing a corrosion control study that evaluated the following treatments:

- Alkalinity and pH adjustment
- Calcium hardness adjustment
- Addition of phosphate or silica based inhibitors.

The evaluation was followed by recommendations to the state of optimal treatment for their system. Since promulgation of the LCR, guidance was developed for utilities to evaluate these treatments. Because of the complexities of corrosion control treatment, evaluations were to be completed on a case-by case basis. Specific pH and alkalinity levels were not recommended, but information on the theoretical solubility of lead was provided to help utilities estimate reductions that might be observed in tap lead levels under various pH and dissolved inorganic carbonate levels (USEPA 1992). Within the pH range of 5 to 10, increasing pH should generally reduce lead levels. Waters with pHs greater than 7.8 and alkalinities between 30 and 100 mg CaCO3/L would generally be considered non-corrosive with respect to lead and maintaining a stable pH in the distribution system was emphasized (USEPA 2003). For water systems using orthophosphate, it was recommend that a residual of at least 0.5 to 1.0 mg/L orthophosphate as phosphorus be maintained in the distribution system along with a pH within the range of 7.2 to7.8 (USEPA 2003).

A comprehensive review of which corrosion treatment approaches have been applied throughout the US since implementation of the treatment requirements of the LCR, and the effectiveness of specific treatment approaches has not been conducted. Since 2002, the states have been required to report 90th percentile lead concentrations to USEPA for water systems serving more than 3,300. The USEPA recently reviewed this data from medium and large water systems throughout the US (i.e., utilities serving more than 3300 people). Table 2.5 displays a summary of this data from monitoring rounds completed in 2003 and 2004 (USEPA 2005a). More than 96 percent of the utilities that serve more than 3,300 people had 90th percentile lead levels that were below the lead action level. The USEPA also reviewed monitoring results from several large water systems that had conducted monitoring in 1992 and/or 1993 and compared that data to results from the most recent monitoring completed by those utilities (USEPA 2005b). Of 166 systems that exceeded the lead action level in 1992/1993, only 15 systems exceeded the action level in their most recent monitoring period. This data does not include information on the optimal corrosion control approach utilized. It could be corrosion control treatment, lead service line replacement or a combination of the two. Therefore, while these reviews do not provide information about the effectiveness of a particular treatment approach in reducing lead and copper levels at the tap, they do identify overall reductions in 90th percentile lead levels throughout the US due to implementation of the LCR.

Table 2.5
Medium and large public water systems exceeding the action level since 2003 (summary from SDWIS/FED data as of January 27, 2005)

Systems Over Action Level since 2003*	Medium	Large	Total
Number of Systems Over the Action Level	97	14	111
Total Number of Systems with monitoring results since 2003	3114	438	3,552
Percent of Systems with results over AL	3.1%	3.2%	3.1%

* Includes sampling rounds concluding in 2003 and 2004

United Kingdom Experience

In 1998 the European Drinking Water Directive specified quality standards for lead in drinking water supplies. These standards were comprised of an interim standard for lead of 25µg/l to be achieved by December 25, 2003 and a final standard for lead of 10µg/L to be achieved by December 25, 2013. These standards apply to a sample of water from the consumer's tap that is representative of a weekly average value ingested by consumers. In the UK water quality is also regulated by the Drinking Water Inspectorate (DWI) who may take appropriate action if drinking water is considered unfit for human consumption. To enable water companies to meet the stringent quality standards for lead the DWI has put in place a regulatory framework of work for plumbosolvency treatment and control and continues to issue guidelines (through information letters) to water companies, generally through government legislation, to enable them to incorporate programs of work into business strategy.

Sources of Lead in the United Kingdom. In the UK water entering drinking water supply systems generally contains insignificant levels of lead. The main source of lead in domestic properties is from lead service line pipes. The second major source of lead is from lead-solder. Traditionally solders in European domestic plumbing systems have contained 50 to 60 percent lead. However the use of lead solder in potable water systems has been prohibited since the 1970s. In the UK there may be as many as 10 million properties affected by pipe-work either through lead service lines or internal plumbing. Water companies own the part of the service from the water main in the street up to the stopcock at the boundary of the property. Beyond this point the owner of the property is responsible for its condition and maintenance. The communication pipe is referred to as the pipe from the main to the customer's boundary while the supply pipe is the pipe from the outlet of the external stop tap up to and including the internal stop tap but not including internal plumbing (Figure 2.2).

Plumbosolvency Control in the UK Plumbosolvency control is a general term used to describe treatment processes to reduce lead concentrations at the customers tap. These processes to control lead levels at customer's taps can be achieved through treatment to reduce the dissolution of lead, through re-lining of lead pipes or by replacing lead-containing materials. In the UK, the following plumbosolvency control processes are used:

- pH control (7.2-7.8)
- Alkalinity
- Orthophosphate dosing (0.5-1.7mg/L as P or 1.5-4.6 mg/L as PO_4)
- Lead pipe replacement

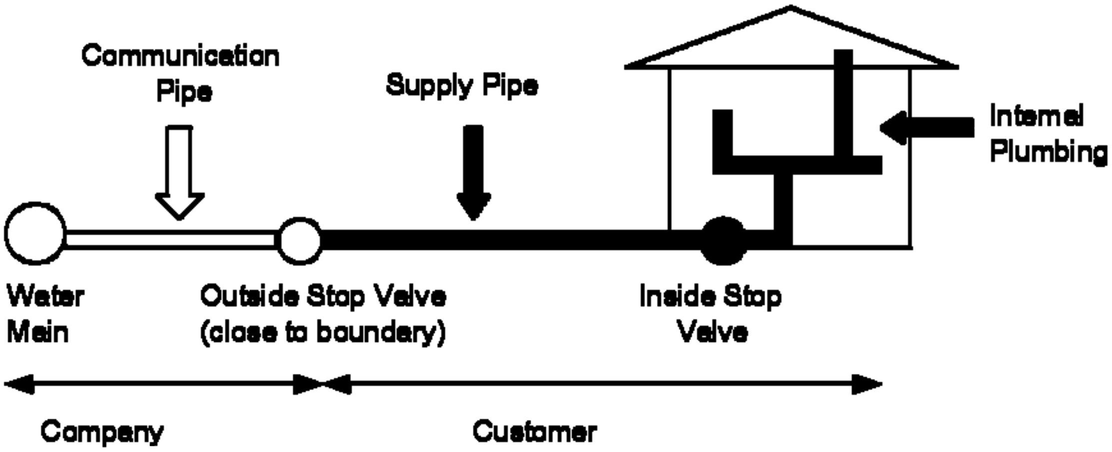

Figure 2.2. Diagram showing typical UK piping configuration

In some cases a combination of approaches may be necessary. Compliance, in particular with the 10µg/L standard, may require some lead pipe replacement. However in the UK it is considered important that reductions in plumbosolvency by chemical treatment are maximized before lead pipe replacement is undertaken. The cost of replacing lead pipes is considerable (an estimate of £8 billion pounds [$15 billion USD] for all UK pipes) and it is thought that any expenditure by utilities to replace only their part of the service pipe may have limited benefits. It is anticipated that significant reduction of lead at some customer's taps may only be achieved by replacing all lead fittings at customer's properties. Table 2.6 outlines the number of samples, taken at customer's taps that were non-compliant with 10 ug Pb/L in 2002.

The preferred treatment process within the UK is addition of phosphate as orthophosphoric acid at the treatment works. The target concentration is usually between 1-2 mg/L as P (3.1-6.1 mg/L as PO_4). To ensure the correct dose is applied, on line orthophosphate monitors are installed at many treatment works while at others, companies rely on grab samples. Infrequent grab sampling is considered inadequate to ensure correct dose. Once the target dose is achieved, it is important to maintain the effective dose throughout the distribution system. The process of orthophosphate dosing leads to the deposition of a highly insoluble lead phosphate deposit on the surface of lead pipes and thus inhibits lead dissolution.

Table 2.6
Percent non-compliance in 2002 from a number of water companies in the UK

Company	No of Tests	No of failures	% Failure rate
1	39	12	30.77
2	7	2	28.57
3	721	87	12.07
4	4661	419	8.99
5	1415	118	8.34
6	517	32	6.19
7	502	29	5.78
8	274	15	5.47
9	1716	81	4.72
10	2781	77	2.77
11	1023	25	2.44
12	213	5	2.35
13	517	12	2.32
14	980	22	2.24
15	1578	35	2.22
16	143	3	2.10
17	481	10	2.08
18	841	10	1.19
19	1706	0	0.00

There are a number of additional factors which effect the concentration of lead dissolving from lead pipes into drinking water. These include the chemical nature of the water, retention time, properties and chemistry of lead pipe, level of oxidant in water, pH, dissolved inorganic material, alkalinity, temperature, size of pipe and age, type of materials and corrosive properties of the water supply. In general soft, acidic waters that are high in dissolved oxygen are more corrosive and will lead to higher levels of dissolved lead. Several studies have demonstrated that the response time for lead reduction after phosphate dosing will vary. The reduction in lead will be proportional to the orthophosphate concentration and many months of dosing may be necessary to ensure that very old and scaled surfaces are adequately protected with a lead phosphate film. Although this may take as long as 36 months, some reduction in lead at the customers tap should be seen within the first 6 months.

In the UK, the DWI provided a model framework from which individual companies could develop a strategy for plumbosolvency control. This framework provided guidelines on data requirements, identification of treatment works that require plumbosolvency control, deciding which treatment is beneficial, guidelines on optimization of treatment and control and on monitoring and control strategies at treatment works and in distribution. Data requirements include chemistry of water, historical data and identification of supply zones. Treatment works for consideration of plumbosolvency treatment should be identified through use of random daytime compliance samples. Random daytime samples are taken from a random property at a random time of day. A 1-liter sample is taken from a drinking water tap without flushing and therefore the stagnation time within the pipe is unknown. Each treatment works should be assessed against the criterion whether 5 percent of samples from zones exceed 10 µg/L. Where more than 5 percent of samples are above the 10 µg/L standard, plumbosolvency treatment should be considered. In addition, the DWI have specified that plumbosolvency treatment will be required to be maintained where there are significant numbers of lead pipes owned by the property owner irrespective of whether the company has replaced all of its lead pipes. The Inspectorate also considers that monitoring should commence immediately after implementation of plumbosolvency treatment. Water companies should consider water quality parameters to be tested at each treatment works, frequency of sampling and reasons for deviation of target water quality parameters. Monitoring and control in distribution should include random daytime sampling for lead and stagnation samples from selected properties supplied by lead pipes before and after treatment (stagnation sampling is normally 30 minutes) and the use of lead rigs. Other water quality parameters such as pH, orthophosphate residual, alkalinity /DIC should also be tested where appropriate. All plumbosolvency treatment and control was to be installed, commissioned and optimized by December 31, 2003.

Individual water companies in England and Wales submitted their strategies on plumbosolvency optimization and control to the DWI in 2002. While it is generally accepted that water companies have fulfilled their obligations to install and commission treatment where required methods for the demonstration of the effectiveness of treatment varies considerably between companies. The most important factor for demonstration of this effectiveness of lead control is the sample type used to detect levels of lead at treatment sites and in distribution. The type and number of samples taken by individual companies to demonstrate effective treatment varies considerably. The most commonly used sample types are random day-time (RDT) samples and 30-minute stagnation samples. In addition the use of lead pipe rigs at treatment works or within the distribution system has been widely used.

Sampling Methods to Demonstrate Optimization. All water companies have to take regulatory compliance samples for lead irrespective of lead treatment optimization. Some companies have opted to use these samples as part of their optimization program. Other companies are using RDT sampling at an enhanced frequency. Most companies use a combination of sampling types. The recommended monitoring frequency includes standard RDT compliance monitoring and a sufficient number of stagnation samples from selected properties. For stagnation samples a minimum of two and a maximum of four properties are generally recommended and monitoring should be at a frequency of three samples from each property in a 7-day period each month. Sampling for lead treatment optimization should also span winter and summer months to identify impacts of temperature on lead levels.

Using RDT sampling has the advantage that the results should indicate the extent of compliance. RDT is simple, inexpensive and more acceptable to customers than stagnation sampling. However because the stagnation time is uncontrolled the results of RDT sampling are far less reproducible than fixed stagnation time sampling. Statistically it is widely accepted that many more samples are needed to give the same amount of information as fixed samples. RDT samples will also contain a number of non-leaded properties. As a consequence the effects of changes to orthophosphate dose may be masked by the results from non-leaded properties. Overall it may prove more difficult to demonstrate optimization.

In general, water companies have found that it can take considerable time and effort to find consumers who are willing to cooperate with the interruptions to their daily life, during stagnation sampling monitoring, even when financial inducements are offered. Customers may become resistant to frequent visits and the drop out rate can be high.

Lead pipe rigs avoid the disadvantages of both RDT and fixed-point sampling. Rigs fitted with new lead pipe will allow the effects of treatment and optimization to be established. However the absolute values from lead rigs may not be directly comparable. Several companies use pipe rigs supplied by different manufacturers. There is little information on how different lead rigs compare. Several companies use more than one type and the operational cycle between rigs often varies. There are currently nine different lead rigs in operation throughout the UK.

Over 70 percent of companies are using more than one sample type (RDT, Stagnation, Rig) to monitor plumbosolvency although the number of sample points and sampling frequency varies considerably. A small number of companies that are using fixed samples rely on customers to take stagnation samples. There is a risk that the consumer may not follow the correct procedure. Some companies use 8-hour stagnation samples from fixed properties or rigs rather than the more usual 30- or 60-minute stagnation samples. Eight-hour stagnation is considered atypical of normal domestic water usage patterns and are used to generate higher lead levels. It is now generally accepted that trends should be checked against RDT. For RDT sampling the regulatory frequency (up to 24 samples per year per zone) is unlikely to be sufficient. For fixed properties and rigs, most companies sample weekly or three times per month.

Most companies monitor a range of other water quality parameters recommended by the DWI and in addition to lead include pH, temperature, orthophosphate, alkalinity (in soft waters), turbidity, TOC and color. Most companies review data collected from all these sample types on a continuous basis, others only quarterly. Most companies also rely on visual analysis of graphical data and few perform statistical analysis.

Studies to compare the reliability of sampling strategies using statistical analysis is currently supported by the DWI. The preferred method of sampling by the DWI is cluster sampling where 30-minute stagnation samples are taken three times within 7 days each month. An analysis of variance is performed on the data and expressed as a function of the number of samples within each property and 95 percent confidence intervals can be generated. From this data it can be concluded that paired 30-minute stagnation sampling and paired RDT sampling from locations with lead pipes requires the least number of samples, while RDT sampling from randomly selected properties would require the most samples. Other statistical analyses that have been performed on sampling data include t-tests and the Mann-Whitney test.

Studies by UKWIR involving extensive analysis of data from a significant number of water treatment works (throughout the UK) conclude that moderate variation in pH does not have a negative effect on lead levels. The reported optimum pH is 7.2-7.8. The most important factor in lead control is control of orthophosphate concentration in distribution. High variability in orthophosphate concentrations resulted in lower percentage reductions in lead. Maintaining a level of orthophosphate above 0.7mg/L as phosphorus (2.1 mg/L as phosphate) appears to be the most critical factor in maintaining lead levels. Several studies have shown that the time period for lead levels in distribution to fall appears to be proportional to the orthophosphate concentration.

Since plumbosolvency treatment began, a number of problems have been encountered with the process control and optimization strategies developed by a number of water companies within the United Kingdom. Table 2.7 details some of the problems encountered.

Table 2.7
List of known problems associated with obtaining plumbosolvency control and optimization.

- Achieving consistent target dose at treatment plant
- Achieving consistent target dose in distribution
- Inconsistencies on laboratory and on site tests
- Performance of dosing equipment
- Maintenance of equipment and adequate training
- Ineffective mixing of orthophosphoric acid
- Enhanced RDT sampling necessary for statistical analysis
- Method and frequency of sampling sometimes inadequate
- Number of zones not responding to phosphate dosing
- No comparison or calibration of lead rigs and inconsistencies in lead pipe rig performance

Lead Scale Formation and Solubility

The response of lead source materials in premise and distribution systems to changes in water treatment is strongly dependent on the mineralogy of the corrosion scales attached to various parts of the system. These determinations are particularly critical for lead compounds, of which there have been many reported. Knowledge of the crystal form of these compounds is a key contribution to models of lead behavior and understanding of lead control via passivation. Accordingly it is critical to develop an understanding of the chemical processes at work involving lead components in distribution systems.

For lead, the dominant minerals found in distribution systems are simple oxides and carbonates. Phosphates are also found, and are increasingly relevant as systems turn to orthophosphate dosing to stabilize lead scales. Table 2.8 presents a list of common minerals and their chemical formulas. There are many others however, and substitutions of other cations or anions are possible, particularly with phosphate compounds.

This array of minerals differs widely in solubility in water depending on the presence of hydrogen, bicarbonate, phosphate, and sulfate ions (H^+, HCO_3^-, PO_4^{3-}, SO_4^{2-}), and the total charge in the solution. Because lead can occupy three oxidation states (Pb^0, Pb^{2+}, and Pb^{4+}), the oxidation level of the water is also critical. This parameter is usually expressed as Eh, or the potential relative to a standard hydrogen electrode.

Metallic lead itself reacts readily with water to produce soluble products and it is only the formation of protective scales that brings the concentration of lead down into reasonable ranges. Probably the most common protective scales under water distribution system conditions are the two lead carbonates: cerussite and hydrocerussite.

Table 2.8
Some common Pb minerals and their chemical formulas

Major Group	Chemical Formula	Comments
Oxides		
Plattnerite	PbO_2 (tetragonal)	Rare in nature, common in distribution systems (DS)
Minium	$PbO \cdot PbO_2$	Rare in DS
Litharge	PbO (tetragonal)	Common in nature and DS
Massicot	PbO (orthorhombic)	Rare in DS
Carbonates		
Cerussite[1]	$PbCO_3$	Common in nature and DS
Hydrocerussite[1]	$Pb_3(CO_3)_2(OH)_2$	Common in nature and DS
Plumbonacrite	$Pb_{10}O(CO_3)_6(OH)_6$	Very rare in nature, sometimes seen in DS
Phosphates		
Hydroxypyromorphite	$Pb_5(PO_4)_3OH$	Common in nature and DS
Chloropyromorphite	$Pb_5(PO_4)_3Cl$	Common in nature and DS
Tertiary lead orthophosphate	$Pb_9(PO_4)_6$, $Pb_3(PO_4)_2$	Rare in nature, sometimes seen in DS
Fluoropyromorphite	$Pb_5(PO4)_3F$	Rare in nature, sometimes seen in DS with fluoridation
Sulfates		
Anglesite	$PbSO_4$	Common in nature, rare in DS
Leadhillite	$Pb_4(SO_4)(CO_3)_2(OH)_2$ (monoclinic)	Rare in nature, rarely found in DS, giving XRD pattern that has features of both
Susannite	$Pb_4(SO_4)(CO_3)_2(OH)_2$ (trigonal)	

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[1] (misspelled cerrusite and hydrocerrusite in the PHREEQC databases and various references)

The Carbonates

Many distribution systems have calcium carbonate scales, usually as the mineral calcite, which does not present a health problem, but can cause serious problems for equipment maintenance. Carbonate minerals are also widely distributed in nature and accordingly have been thoroughly studied. There are several lead carbonates but two are dominant, cerussite, which has a structure like that of aragonite, and hydrocerussite. Both are frequently found as weathering products of lead ore minerals, so again there is a wide literature on their mineralogy and chemistry.

A useful way to compare different lead minerals is to use concentration versus pH diagrams (Figure 2.3). These assume equilibrium between the mineral and the solution and also require mathematically solving a set of simultaneous equations involving ion-pair formation in the solution. These equations are embodied in the computer codes such as PHREEQC, which is the code used for this set of diagrams. The y-axis is total lead, which comprises Pb^{2+}, Pb^{4+}, $PbCO_3^0$, $PbCl^+$, etc. Moving up on the diagram, there is first a region of solution only, with no minerals stable. At about 10^{-6} moles/liter, one or the other of the carbonates should precipitate. At this point, lead levels in the solution should not go any higher, because any addition of lead would be compensated by growth of additional lead carbonate. If for some reason the carbonate does not form (for example in very low alkalinity waters), the solution continues to increase in lead content until litharge forms at lead concentrations in the neighborhood of 10^{-3} moles/liter. This lead level is high and most utilities strive to convert any lead oxide (PbO) in the distribution system into one of the carbonates. Even equilibrium values with respect to the lead carbonates are still above the LCR action limit, however. In practice, a well-developed lead carbonate scale does provide protection, because only a portion of the water in the system is in contact with the lead service lines or lead-containing plumbing materials. Another reason why the lead levels observed are lower than the apparent solubility of the minerals in the diagrams is that in environmental systems, solids recrystallize over time into more stable and insoluble phases. While technically there is only one thermodynamically correct solubility constant, in reality, metastability rules, and the observed solubility would be expected to change and decrease as the scale ages and becomes more ordered. Normally, utilities with well-developed lead carbonate scales will be able to keep lead levels at the tap below the action level. Lead in equilibrium with lead carbonate ($PbCO_3$) is virtually independent of pH at dissolved inorganic carbonate (DIC) levels of 60 mgC/L and higher. However, at 20 mg C/L, there is a strong solubility minimum at pH about 9.8 (Schock et al. 1996). Also note that if there is an under layer of litharge, mechanical removal of the cerussite layer could lead to a sudden increase in lead levels.

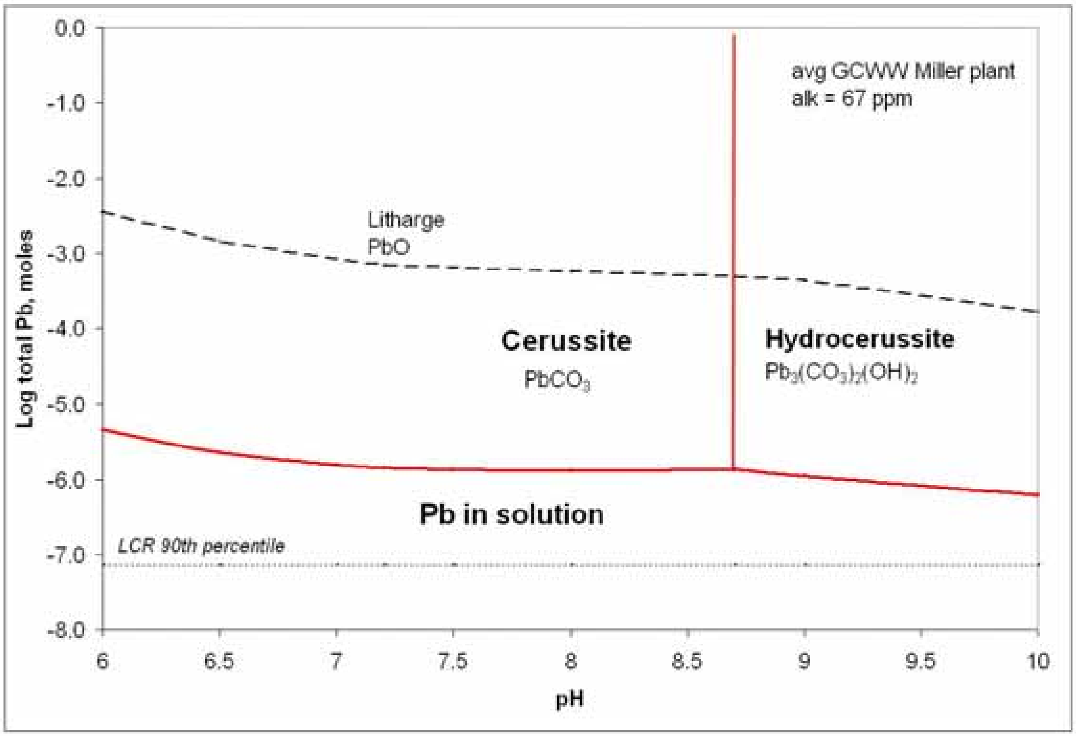

Figure 2.3. pH-concentration diagram for the Pb carbonates. (PbO is shown for comparison. Speciation based on the PHREEQC code using the MINTEQ database and the solution parameters given in Table 2.9.)

Lead oxides

The most common lead oxide seen in distribution systems is litharge, which is quite soluble (Figure 2.4), but can occur as a layer between the metal surface and an overlayer of lead carbonate. Possibly it forms within the scale by reaction between native lead and the carbonate layer.

Plattnerite is much less soluble, but is stable only at very high Eh values (Schock et al. 2001; Schock and Giani 2004). Such conditions can be achieved in distribution systems with high chlorine residuals throughout and with very low concentrations of organic matter. If a protective plattnerite layer is present, lead levels can be improved by raising the pH above about 8.5. Note, however, that supersaturation with respect to calcium carbonate ($CaCO_3$) as calcite occurs in this model system at pH 8.01. Therefore raising the pH beyond the low 8s is likely to result in an increase in calcium carbonate scale formation.

Table 2.9

Solution parameters used in generating equilibrium diagrams. Based on average Greater Cincinnati Water Works finished water from Miller plant

Units	
Temperature	23.0 degrees C
Alkalinity, mg/L	67.0 as CaCO3
Na, mg/L	28.0
Cl, mg/L	28.0
SO_4^{2-} mg/L	74.0
Ca, mg/L	37.0
Mg, mg/L	8.6

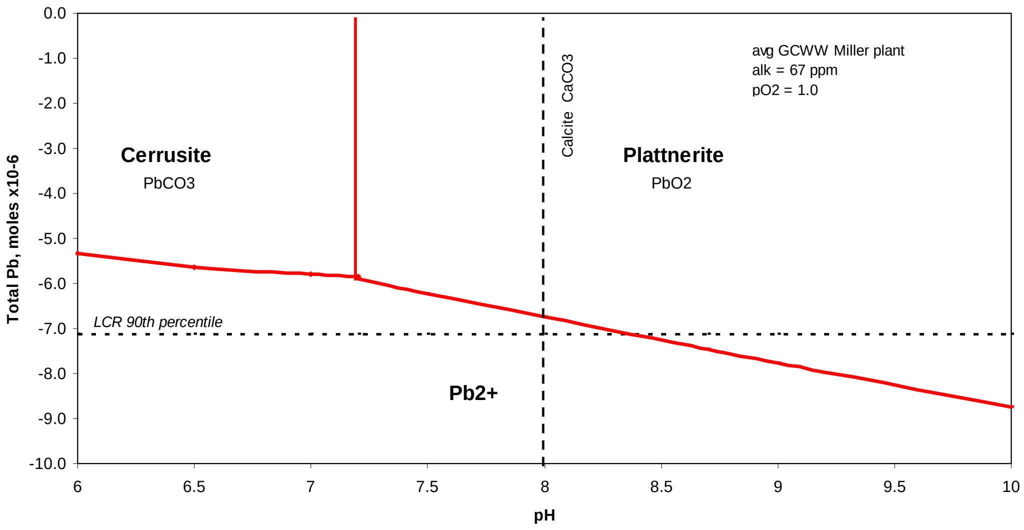

Figure 2.4 Plattnerite-cerussite relations at very high Eh. The Eh values for this diagram correspond to the upper stability limit for water at a given pH. Water with free chlorine would have slightly higher Eh. (Source of MINTEQ database: Allison, J.D., et al. 1990)

The importance of plattnerite is that it can revert to more soluble lead minerals if the Eh subsequently drops (Figure 2.5). Lytle and Schock (2005) presented experimental evidence for ready reversibility of the plattnerite-cerussite transition. A possible explanation for increases in lead in systems that change from chlorine to chloramine disinfection, may be that the Eh is reduced below the stability level of plattnerite, allowing litharge to temporarily control lead levels (Edwards and Dudi 2004; Schock and Giani 2004).

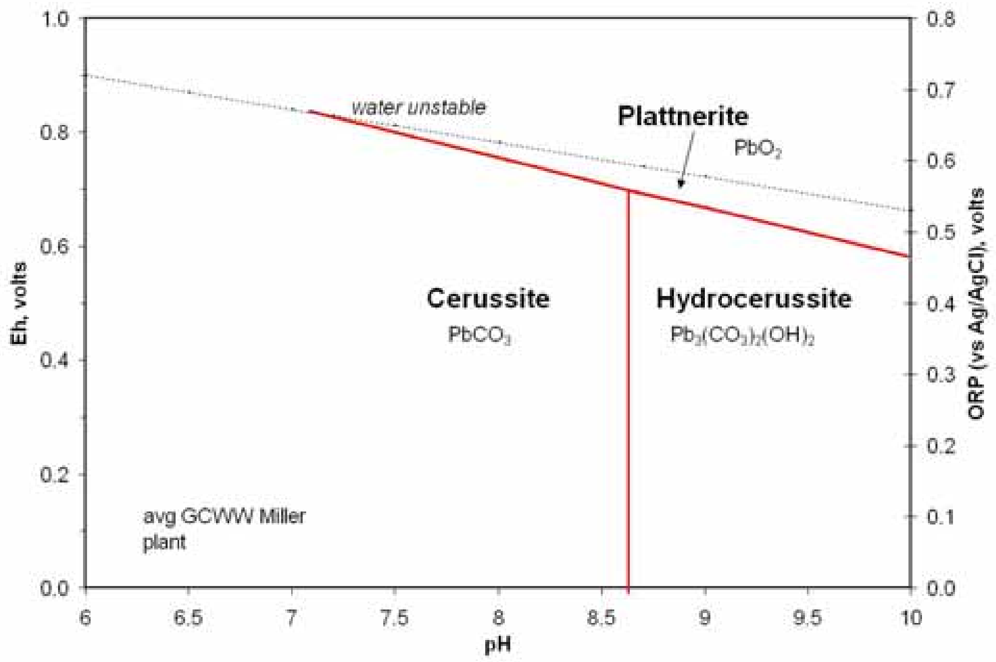

Figure 2.5 Eh-pH diagram for the Pb carbonates and the oxide plattnerite under alkaline conditions

Lead phosphates

A popular strategy for control of lead release is addition of phosphate, either as orthophosphate, zinc orthophosphate, or a polyphosphate blend. Schock et al. (1996) contains a detailed discussion of historic experience with phosphate and of equilibrium modeling. Figure 2.6 presents a simplified view of phosphate behavior using hydroxypyromorphite as an example. Adding orthophosphate greatly reduces the equilibrium solubility of phases like hydroxypyromorphite and its chloride and fluoride cousins and should therefore reduce lead at the tap. Similar results are sometimes obtained with polyphosphate addition, possibly because the polyphosphates revert to the monomeric orthophosphate in the distribution system (Schock and Clement 1998, p. 21). However, in the absence of reversion, polyphosphates may well be detrimental because they prevent the formation of insoluble lead compounds (AwwaRF 1990) or enhance release of pH particulates (Cantor et al. 2000; Edward and McNeil 2002).

Note that the amount of lead in solution is appreciably lower than for equilibrium with the carbonates and that the levels approach the LCR limit. However, there is a pronounced solubility minimum and much of the benefit could be lost by raising the pH beyond 8 when using orthophosphates. Chloropyromorphite is appreciably less soluble than hydroxypyromorphite in the MINTEQ database (Hopwood et al. 2002), so the incorporation of even small amounts of chloride or fluoride into the structure could change the solubility behavior appreciably. Likewise, carbonate and sulfate substitutions are known for phosphate minerals and might increase or decrease solubility. Finally, PHREEQC modeling shows strong supersaturation with hydroxyapatite at all levels of orthophosphate addition for the whole pH range in Figure 2.6. It may be possible that the first phase to form is actually an apatite that subsequently reacts to adsorb lead from solution. This takes us into the realm of kinetics, which is not well understood for mineral systems in general, and is particularly poorly understood for the time frame and solution conditions presented by distribution systems.

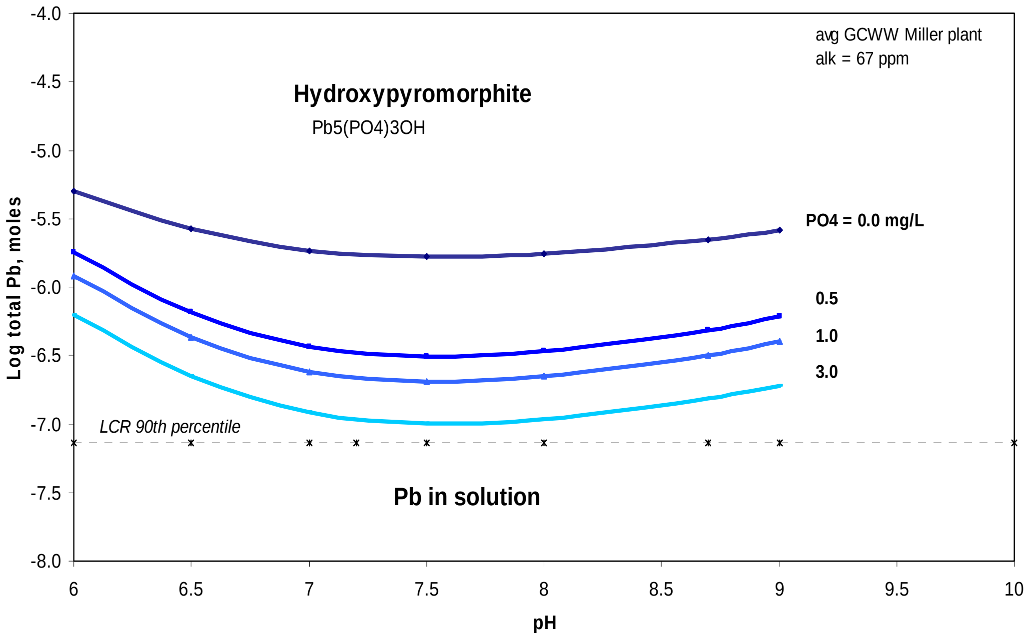

Figure 2.6 Effect of phosphate addition on Pb in equilibrium with hydroxypyromorphite.

RESEARCH SUMMARY

The following sections summarize the research conducted for this project. Detailed discussions of the approach, methods, materials, and results can be found on the CDROM accompanying this report.

Survey

A national survey was developed to generate a snapshot of typical industry service line jurisdiction issues and replacement techniques, physical characteristics of service lines, and the presence of lead sources under either utility or customer control. This survey obtained the following key information:

- Legal (ownership) issues related to service line installation, repair, and replacement
- Typical service line lengths

- Typical costs of service line replacements
- Use of leaded materials in the distribution system (meters, leaded joints, fittings, valves).

Results from this survey were compared to information obtained in previous surveys. The average total length of service lines (main to residence) and average replacement costs reported from the survey are shown in Tables 2.10 and 2.11.

Results from this survey indicate that:

- Estimates of average lengths for utility owned and customer owned service lines are similar to results obtained from previous surveys.
- Average service line lengths and costs for replacement varied considerably between utilities.
- Utilities generally have authority of the service line from the main to the curbstop, and own the meter, although there are some exceptions.
- Property owners are responsible for replacement of their portion of the service line.
- Specifications for installation of no-lead components are being implemented at several of the utilities surveyed, and a smaller number have programs to replace lead containing components in their system.
- For the utilities responding, there did not seem to be a good understanding of the extent of leaded component use in the system.

Table 2.10
Average service line lengths from survey

	Average Length Utility Portion, ft	Average Total Length of Service Line, ft
Urban	25 (3-60)	55
Suburban	27 (0 -60)	68

Table 2.11
Typical service line replacement costs from survey

Average Cost of Replacement, $/service	
Utility Portion	**Customer Portion**
$1,261 Range ($250-$3000)	$2,300 Range ($600-$4000)

Case Studies

Several utilities provided historical information to document their experiences with partial and full lead service line replacement, leaded meter replacements, evaluations of lead levels at the tap, and implementation of no-lead fixture replacement programs. In addition, Thames Water provided a detailed case study of the effectiveness of orthophosphate treatment in their system. Utilities that provided information for case studies of their experiences included:

- Greater Cincinnati Water Works, Cincinnati, Ohio

- District of Columbia Water and Sewer Authority (DCWASA), Washington D.C.
- East Bay Municipal Utility District (EBMUD), Oakland, Calif.
- Lost Angeles Department of Water and Power (LADWP), Los Angeles, Calif.
- Louisville Water Department, Louisville, Ky.
- Madison Water Department, Madison, Wis.
- Newport News Water Works, Newport News, Va.
- Philadelphia Water Department (PWD), Philadelphia, Pa.
- Portland Water Bureau (PWB), Portland, Ore.
- San Francisco Public Utility Commission, San Francisco, Calif.
- Seattle Public Schools, Seattle, Wash.
- Thames Water, London, United Kingdom

The following section contains a brief summary of each case study, and the key information gleaned from each. Complete case study write-ups can be found on the CDROM accompanying this report (Appendix B).

Greater Cincinnati Water Works

The Greater Cincinnati Water Works (GCWW) has conducted several studies evaluating the impacts of partial versus full replacement of lead service lines, impacts of flushing on lead levels measured at a residence, and the potential for components to release lead. They found that high lead levels were measured at the tap after both full and partial replacement, but the lead levels measured after full replacement were lower than the levels associated with partial replacement. They also concluded that partial replacement did not result in benefits over leaving the service line in place over the long term, but full replacement reduced lead levels overall.

District of Columbia Water and Sewer Authority

The District of Columbia Water and Sewer Authority (DCWASA) is conducting replacement of at least seven percent of lead service lines each year as required by the USEPA, giving highest priority to those lines with highest lead levels. In coordination with the USEPA, they have developed a protocol for developing lead profiles which has given them an opportunity to study the possible origins of lead levels at the tap. This sampling protocol involves collection of consecutive samples at the tap after a minimum 6-hour stagnation period. DCWASA has also conducted a study to determine the best method for performing a partial lead service line replacement. They found no difference in lead levels measured at the tap when different construction equipment was used, and lead levels were reduced due to flushing immediately after replacement. Finally, a study of the contribution of bronze meters to tap lead levels concluded that lead can be released from meters in a laboratory setting, but field sampling indicated that in-house plumbing was the major contributor to lead measured at the tap.

East Bay Municipal Utility District

The East Bay Municipal Utility District (EBMUD) is currently implementing a “no lead” meter and fitting replacement program, with the ultimate goal of removing all sources of lead up to premise piping. The increased costs of the program are considered acceptable, especially in light of potential legal and potential financial ramifications that Prop 65 poses for the utility. To date EBMUD considers the program to be a success at protecting public health with inconsequential additional financial burden.

Los Angeles Department of Water and Power

The Los Angeles Department of Water and Power (LADWP) has implemented a No-Lead Brass Program to change out its leaded brass parts with components made using non-leaded alloys. They intend to replace all meters (~700,000) by 2016, with an annual replacement goal of 40,000 meters. Current information indicates no observed differences in structural performance between historical components and these non-leaded components. Costs of non-leaded components are currently higher than their leaded counterparts (20 to 30 percent), but when material costs are evaluated in perspective to the entire cost of the service installation, the overall increase in costs is significantly less (2 to 5 percent). As more utilities install non-leaded components and the market expands, the material cost differentials should decline.

Louisville Water Company

The Louisville Water company (LWC) has implemented several programs to reduce household lead concentrations including a lead service line replacement program, a meter replacement program, and a cleaning and cement lining program for pipelines with lead or leadite joints. The lead service line renewal program was conducted in association with their main replacement program in the 1980s, at a cost estimated to be approximately 50 to 70 percent of the cost of individual service renewals. Extensive tap monitoring at sites where lead service lines had been replaced found that flushing for three minutes prior to taking the "first draw after renewal" sample tended to decrease the total lead content in almost all samples.

To address the lead content of meters, LWC included a “no lead” provision in their specifications that requires the installation of meters and fittings whose components, individually, do not exceed a lead content of 0.25 percent. LWC’s “no lead” meter, fitting and lead service line replacement programs are currently scheduled for continuance with the ultimate goal of removing all sources of lead up to premise piping. The increased costs of the program are considered acceptable. To date, LWC considers the programs to be a success at protecting public health with inconsequential additional financial burden.

Madison Water Utility

The Madison Water Utility (Madison) has undertaken a full lead service line replacement program to meet the requirements of the LCR, with a goal of replacing all lead service lines in the City by 2011. Since the customer has authority of the service line from the curb-stop to the building, the Madison Common Council approved a plan to place half the cost of replacing customer lead service lines on sewer rates. This decision was justified by showing a substantial avoided cost to sewer customers by implementing a complete lead service line replacement program, as opposed to adding corrosion control chemicals to drinking water which would need to be removed at the wastewater treatment plant.

Water quality data collected to assess the success of the full lead line replacement program suggests that dissolved lead concentrations are lower after lead service line replacement, but total lead concentrations are erratic, and continue to be erratic for several years.

Newport News Water Works

Newport News Water Works (Newport News) replaces approximately 8,500 meters annually through their meter replacement program, plus incidental replacements that happen as a result of other types of work. In 2004, Newport News revised its meter specification by asking for two sets of pricing (with lead content/no lead content) to determine if a cost factor would be involved in the decision to use no lead meters. The 2004 bid results showed that the same meter supplier again had the most price-competitive bid response even with the non-leaded product and was awarded the meter contract for the new contract period. The case study in the accompanying CDROM contains Newport News' bid documents for no-lead meters as an example for other utilities considering use of non-lead meters.

Philadelphia Water Department

The Philadelphia Water Department's (PWD) jurisdiction with respect to lead service lines is unique in that the entire line is owned by the customer. While replacing mains, PWD replaces lead lines with copper from main to the curbstop and encourages the homeowner to take care of the remaining portion at the same time. PWD has also conducted investigations of 1) tap lead levels at sites with and with out lead service lines, 2) faucets as potential lead sources, and 3) tap sampling methods. When comparing lead level results from homes with and without lead service lines, the 90th percentile lead results for homes without lead service lines was higher than the 90th percentile for homes with lead service lines, suggesting that source of lead in the premise piping may be more important in determining exposure to lead in drinking water in Philadelphia.

Portland Water Bureau

The Portland Water Bureau (PWB) proactively addressed lead goosenecks on utility-owned plumbing as early as 1982. During a 16-year program, the PWB removed and replaced 12,562 lead gooseneck at a cost of approximately $12 million dollars. The program removed approximately 19,000 – 25,000 linear feet of lead from the distribution system. Because the goosenecks were typically associated with homes constructed during the early half of the 1900s, the goosenecks were located in residences that were outside the USEPA definition of Tier 1 homes for LCR compliance monitoring. Locating, removing, and replacing the connections removed lead from the distribution system that would not have been otherwise monitored under LCR requirements.

San Francisco Public Utility Commission

The San Francisco Public Utility Commission (SFPUC) has completed several lead source reduction measures such as the discontinued installation of lead joints in water mains (1983) and the removal of all known utility-owned lead service lines (1983-1988). More than 10,000 lead service lines were removed from the system during this time. The SFPUC has several on-going lead source reduction programs including a meter replacement program and a lead-free (<8 percent lead) faucet distribution program. They also conducted a series of bench-top lead release tests to better understand the sources of lead (consumer's plumbing versus water system's plumbing) and to assess the merits of switching to non-leaded (<0.25 percent lead) in-line components. The testing program focused on leaded and non-leaded water meters (5/8-inch, 1-inch and 2-inch) and curb stops (1-inch to 2-inch). Another program evaluated four types of non-leaded faucets. Results indicated that 1) there were significant differences in the amount of lead released between brands of non-leaded meters; 2) curb stops had similar or higher lead release rates as meters; and 3) some non-leaded faucets released more lead than others.

The SFPUC also initiated a pilot-scale program to test non-leaded curb stops under field conditions to evaluate operations and maintenance issues. After 1 year of installation, these non-leaded curb stops were reportedly functioning well.

For the pilot faucet replacement program, each preschool or daycare center was contacted and offered a free non-leaded faucet. By October 2000, about half of San Francisco's 440 childcare centers had received non-leaded faucets. Due to the success of the pilot faucet replacement program, SFPUC also initiated a faucet distribution program for residential customer. Customers were given the opportunity to purchase a kitchen faucet for $10, a savings of $110.

Finally, the SFPUC implemented a non-leaded meter replacement program with a goal of replacing 7,000 to 8,000 meters annually over a 20-year period. As of October 2005, about 13,000 non-leaded meters have been installed. The sizes of meters included in the program range from 5/8-inch to 2-inch.

Seattle Public Schools

The Seattle Public Schools (SPS) purchases water exclusively from Seattle Public Utilities (SPU) for drinking water, other potable uses, and fire protection service. More than 60 percent of the school district structures are plumbed primarily with galvanized steel piping, which is over 40 years old and is moderately tuberculated." (Boyd et al. 2005). In 2004, SPS initiated a comprehensive testing program to identify existing endpoint devices (i.e., water fountains, classroom and kitchen faucets) with elevated lead levels. Drinking water samples were drawn and analyzed for every school across the system. Samples were typically 250 mL first-draw samples representing water that had been standing overnight in water fountains and the connective piping system. A replacement program was developed for each individual school which included full or partial pipe replacement, replacement of drinking water fixtures (i.e., water fountains, faucets), replacement of flexible connectors and shut-off valves, and in some cases installation of point-of-use filters that were NSF certified for lead removal. Where brass components were replaced, non-lead (~0.03 percent lead) brass components were utilized.

In 2005, a laboratory testing program was conducted to determine lead releases into drinking water associated with new water fountain fittings and plumbing components installed in SPS facilities (HDR/EES 2005). Stagnation test results showed that a reduction in lead concentration to <10 ppb, generally occurred within the first 48 hours of stagnation (HDR/EES 2005). Several of the low-lead brass bubblers experienced periodic lead spikes, which could be attributed to releases of particulate lead. For the stainless steel bubbler evaluated, particulate release and/or lead concentration drops to < 10 μg/L appeared to occur within less than 30 hours. Preliminary results of flow-through tests for both types of bubblers showed that particulate removal and/or lead concentration drops to <10 ppb occurred within approximately 4 hours of starting the test (HDR/EES 2005).

Preliminary stagnation test results for brass elbow connectors showed that lead releases on the order of 800 and as high as 1,400 ppb occurred during the initial 65 hours (2.7 days) of the test (HDR/EES 2005). Passivation to a lead concentration in the range of 200 to 400 ppb occurred after 140 hours (5.8 days) of exposure in these preliminary findings. Preliminary stagnation test results for flex connectors with brass ends showed that the initial lead releases on the order of 110 up to 250 ppb occurred during the initial 48 hours of the test (HDR/EES 2005). The volume of water contained in these fittings was small however (3 mL for brass elbows and 33 mL for flex connectors), making their overall contribution to a 250 mL sample relatively small. Passivation to a lead level of about 15 ppb occurred at 265 hours (11 days) in these preliminary tests.

Thames Water, UK

It is estimated that there are approximately 1.4 million lead service line pipes still in operation within the Thames region equating to approximately 7200 km of pipe. Virtually all contamination at customers' taps arises from lead service line pipes, lead-lined tanks, lead solder joints and leaded copper alloy fittings. All customers where the lead level is >25 μg/L (based on 30-minute stagnation samples) qualify for free lead communication pipe replacement regardless of whether the customer replaces their lead pipe. All customers who have lead levels between 10 μg/L -25 μg/L will qualify for free lead communication pipe replacement providing the customer first replaces all their lead pipe work (supply pipe and internal plumbing).

Orthophosphoric acid dosing for corrosion control was introduced at 44 treatment works in the Thames region between 2001 and 2003. The recommended dose for surface waters was set at 1.5 mg P/L and for groundwater 1.0-1.2 mg P/L, with an optimum pH for phosphate dosing set between 7.2 and 7.8. During 2003 and 2004, a review of water supply zones where orthophosphoric acid was fed indicated that most areas were showing a reduction in the lead levels observed at customers' taps. The size and source water differed within and between schemes and also at different times of the year. In some groups the response to orthophosphate dosing has been very quick and dramatic, whereas other groups have been slower to respond. Although overall compliance is above 95 percent (to 10μg/L), however specific hot spots within a proportion of these lead zones still occur.

Pilot Evaluations

Three pilot evaluations were completed to study lead level contributions from various lead containing materials. These included evaluations of residential brass kitchen faucets at the PWB, residential meters at the SPU, and lead service lines at the Washington Aqueduct (WA).

Portland Water Bureau Faucet Study

A 12-month study of six commercially available residential brass kitchen faucets was conducted at the PWB to determine lead and selenium release at various stagnation times as well as during continuous long-term simulated residential use. The experiments utilized a test rig that consisted of six faucets mounted side-by-side for concurrent testing. The faucets installed included a faucet manufactured with non-leaded brass and a faucet labeled as California Prop 65 compliant. Additional testing was also completed on these faucets, including identifying which of the numerous components inside the faucets contained lead, analyzing the faucets per the ANSI/NSF Standard 61 Section 9, evaluating particles that had accumulated in the aerators of the faucets, and conducting analysis of the scales formed on the faucets' internal surfaces. A complete discussion of the pipe-rig set-up, analysis, and results are included in Appendix C on the accompanying CDROM.

Lead release from the six brass residential kitchen faucets tested at the PWB was found to be localized to a specific 60 mL sub-volume within a given faucet. The net contribution of a faucet to a 1-liter compliance sample was generally found to be less than 3 µg/L. However, the faucets were also found to release random high concentrations of lead that would result in elevated concentrations in a calculated aggregate 1-liter sample. Approximately half of the lead in a 6-hour stagnation sample was released in the first 30 minutes of the stagnation period. An evaluation of selenium release was also conducted, and the non-leaded faucet was found to release 0.6 µg/L selenium or less for each of the sub samples taken, significantly less than the selenium MCL of 50 µg/L.

The sampling flow rate was found to have an impact on the total lead detected in 1-liter samples from the faucets. The amount of lead detected correspondingly increased as the sampling flow rate increased from 1-L/min to 4-L/min. Evaluation of the lead content of the various parts of each faucet found that individual components were manufactured from different materials, including brass with varying lead content, plastic, copper, and a non-leaded brass. This testing found that there was no correlation between lead content in the metals and the amount of lead released from the faucet. In addition, the non-leaded faucet utilized non-leaded components for all parts with the exception of the spout and the cold water tube which were manufactured with the same materials as the other faucets evaluated.

Testing triplicates of the PWB faucets using the ANSI/NSF Standard 61, Section 9 protocol found that some of the faucets exhibited substantial variability in lead release. The highest statistical lead Q value was from the faucet identified in the PWB testing as the one with the highest initial lead release. In addition, the Standard 61, Section 9 protocol testing identified a high Q value for the non-leaded faucet, which matched the high release detected during long-term testing. Identification of the metal composition of the individual faucet components found that the lead content of the alloys used to manufacture the various faucet parts (cold water fitting, cold water tube, the lower and upper valve bodies, the spout receiver, and the spout), ranged from 0.1 to 3.4 percent lead.

An elemental analysis of the amorphous compounds that had accumulated on the interior part of the faucet aerator determined that there was no lead retained in this layer. As a result, the aerators used in the PWB faucets did not accumulate particulate lead. The hypothesized reason was that the openings in the aerator are substantially larger than any lead particulates and as a result, any particulates released by the faucet body may have passed through the openings. Analyses of deposits on the interior surfaces of the faucets found that while there was evidence of small patches of scale, none of the faucets showed extensive scale development, that is, continuous passivating scales did not form over the one-year period of the experiment. Instead, the dominant process was the formation of a zinc-depleted layer on the internal surfaces of the faucets. Lead released from the faucets, as determined in sequential sampling after 6-hour stagnation, tended to increase rather than decrease with time, which is consistent with progressive dezincification producing a porous surface layer through which lead can diffuse more rapidly, or from which lead particulates can be detached more readily with time. Another possible hypothesis is that small (sub-micrometer) sized blebs of lead may occur in the exposed brass which may be easily dissolved by internal galvanic currents within the brass.

Seattle Public Utilities Meter Study

Six residential water meters were used in side-by-side testing at the SPU Water Quality Laboratory to identify their potential lead and copper contributions to drinking water in first-draw stagnation samples. The meters ranged in service age from new, never used units to one that had been in service for 40 continuous years. Five of the meters were brass with up to 8 percent lead content, and one was a newer “no-lead” brass in which the lead content is less than 0.2 percent, and bismuth and selenium are used in its place. A complete discussion of the set-up, analysis, and results of this study are included in Appendix C on the accompanying CDROM.

This study determined that older water meters in the SPU Cedar system can contribute lead to the drinking water at detectable levels, but significantly less than the action level. These older meters were found to be minor contributors to the overall lead exposure at SPU due to the well-passivated surface that limited metal corrosion. Experiments with a new no-lead Envirobrass meter found that the new alloy released very low, but again detectable, levels of lead, bismuth, and selenium. Bismuth is not regulated while selenium was found at concentrations significantly less than the MCL. Conversely, a new leaded brass meter was found to release significant amounts of lead initially. The experiments also found that after 7 months of simulated intermittent use, the new brass meter was still releasing approximately 7 μg lead in a composite 1,750 mL sample (4 μg/L). In comparison, the 4-year old and 19-year old meters by the same manufacturer released 2 μg lead or less in the same tests (1.1 μg/L). A preconditioning period would be useful to passivate the meter interior and reduce the initial lead release in new brass meters. However, these results show that this passivation period for SPU is some time between 1 and 4 years, if Cedar tap water is used.

For most of the meters, an increase in flow rate from 1 L/min to 4 L/min did not result in increased lead levels. The exception was the new brass meter. The new meter was found to have increased the mass of lead released immediately after the flow rate change. After 8 days of intermittent flushing at 4 L/min, the lead release had decreased to nearly the same level as before the flow rate increase.

The study also found that a physical disturbance to water meters, especially older meters, can have a significant negative impact on developed corrosion scales. The scales were found to be dislodged from the surface and resulted in very high lead levels in the water. A period of 63 days of intermittent flushing at 1 L/min for 3 hours/day was required before the lead levels stabilized below the action level. This information could be important to consider when planning such construction activities as main and service line replacements, utility relocations, or nearby street improvements, where moving and shaking of old meters could occur.

Scale analyses of the interior surfaces of the meters indicated that the scales consisted of mixtures of lead and copper oxides, copper carbonate and iron oxides. All meters (including the non-leaded brass meter – Meter 5) exhibited dezincification with the exception of the oldest meter (Meter 4). Meter 6 was a new, leaded meter and SEM analysis indicated the presence of a lead carbonate scale, most likely hydrocerussite, even though the meter had never been in service.

Washington Aqueduct Lead Service Line Pipe Rig

A pilot study using excavated lead service line piping from the DCWASA distribution system was conducted by the Washington Aqueduct (WA) to evaluate a variety of corrosion control treatment options. Water was circulated through the sections of lead service line piping that had been installed in the pilot apparatus, and water quality samples were collected and analyzed for total and dissolved lead, plus a variety of other parameters. This evaluation was a separate study, not funded or managed through this project; however data was shared with the project team to provide additional information on lead release from lead service line piping.

Issues related to the comparability of lead pipe specimens originally installed in the racks, operational control of influent pH, alkalinity, and orthophosphate levels to the racks, as well as the potential for temperature effects, complicated the interpretation of water quality effects on lead release from the lead pipes used in the WA study. Therefore, results obtained by the Aqueduct were used to indicate general trends in the amount of lead derived from lead piping and the impact that orthophosphate treatment may have on lead levels, rather than relative contributions of lead pipe to lead levels at the tap. Slight increases in lead release may have been caused by switching from free chlorine to chloramines. High particulate lead was measured in racks using orthophosphate, and it took from 7 to 9 months for lead levels to stabilize in the racks. The rack with no inhibitor (Rack 4) had a higher percentage of dissolved lead than in racks with an inhibitor.

Scale analyses of lead pipe specimens from each rack indicate a heterogeneous assortment of original scale types, with particularly variable surface-most scales. In general, there was a greater abundance of litharge close to the pipe surface, whereas pyromorphite and plattnerite were abundant in the next layer. The lead carbonates were distributed relatively evenly in these two layers, with hydrocerussite dominant over cerussite in all cases. A final thin layer was rich in iron and manganese oxides, which were X-ray amorphous, but were detected in SEM-EDS measurements. It is not known to what extent these materials convey protection from lead leaching from the underlying scales. Visual inspection of the scales indicates many cracks. If these are present *in situ*, then the surface layer would not be protective. There was also appreciable vanadinite, a lead vanadate mineral which has not been reported from other systems. The source of the vanadinite is unknown, but was found in both the aqueduct pipe loops and in the distribution system, as reported by Schock et al. (2008).

Field Evaluations

Field evaluations of tap lead levels measured from residential sites with various existing lead sources in the service and premise piping, and the impact of replacing these sources on lead levels measured at the tap, were conducted at several utility locations. The overall objectives of the field monitoring activities were to:

- Identify sources of lead in service and premise plumbing in order to assess the relative contribution of these sources in relation to lead levels at the tap,
- Evaluate changes in lead levels after lead service line or faucet replacement, and
- Assess the impact of pipe cutting techniques on lead levels at the tap.

Field monitoring activities were conducted at the Madison Water Department, Madison, Wis.; Boston Water and Sewer Commission (BWSC), Boston, Mass.; District of Columbia Water and Sewer Authority (DCWASA), Washington, D.C.; Toronto Water Department, Toronto, Ontario; Framingham Water Department, Framingham, Mass.; and the Metropolitan District Commission (MDC), Hartford, Conn. Monitoring consisted of collecting sequential tap samples after a minimum 6-hour stagnation period and analyzing samples for total and dissolved lead. Site surveys were completed at all sites to identify the length, diameter, and type of piping from the faucet to the service connection. This information was used to calculate the water volume contained in the premise plumbing and service piping in order to determine the number of sequential samples to collect. Detailed discussions of the protocols and results from this field monitoring can be found in Appendix F on the CDROM accompanying this report. Results are summarized by utility, and then as general conclusions.

Madison

Lead measured during field sampling at Madison was mostly in particulate form, and particulate lead levels increased in flushed samples immediately after full lead service line replacement. By 2 months after replacement the total and particulate lead levels from standing and flushed samples were at or near the level of detection (1 μg/L), and first-liter lead levels measured after replacement were lower than levels measured before the lead service line was replaced. Results of pipe film analyses indicate that lead is sorbed to iron and manganese scales on the pipe wall and that a layer of relatively insoluble lead dioxide covers the pipe wall and prevents the release of lead into the water. As these scales release particulates into the water, the lead may be carried along resulting in an increase in total lead concentrations measured in the water. In the absence of iron and manganese scales on the lead pipe wall, very low total lead concentrations were seen in the water.

The combination of lead service lines with iron/manganese scales may put individual sites at risk for the high total and particulate lead. Removing the lead service line resolved the elevated lead problem within 24 hours at the four field study sites, and lead levels were still low after 2 months. However, based on previous evaluations at Madison (see Case Study in Appendix B on the CDROM) it may still be possible for lead particulates that have accumulated throughout the plumbing system to be released into the water at random times for years after the lead service line has been removed.

DCWASA

With the exception of the samples collected 1, 2, and 3 days after replacement, the majority of lead measured at the DCWASA field study sites was in dissolved form. In general, sequential samples collected before lead service line replacement were below the action level of 15 μg/L, with the exception of selected sample volumes representative of the lead service line at three sites and the premise piping at one site. Replacing the lead service line resulted in high particulate lead levels for 2 to 3 days after replacement at three of the four sites. At a site where a full lead service line replacement was completed, total lead levels were lower by 3 days after replacement when compared to levels measured before replacement. However, at the sites where partial lead service line replacement took place, lead levels were still elevated 3 days after replacement. Lead levels were generally low in flushed samples, with the exception of samples collected immediately after the replacement at one site, and one sample collected before replacement at another site due to construction.

Lead level results collected 1 or 2 months after replacement indicated that removal of the lead service line (partial or full) did not affect LCR compliance results from before replacement (all sites were in compliance before replacement and by 1 or 2 months after replacement). The chemistry of the internal scales on lead service line pipes excavated from DCWASA found that, in addition to lead, the pipes were rich in iron, manganese, and vanadium, with particularly high vanadium (up to 5600 mg/kg) measured on one specimen. The scale from the lead pipes was dominated by plattnerite, with lesser amounts of pyromorphite, cerussite, litharge, calcium-lead phosphates, amorphous manganese oxide, and lead vanadate (vanadinite).

Toronto

The majority of lead measured from the Toronto field study sites was in the dissolved form, with the exception of high particulate lead measured from the initial two volumes collected after partial replacement at one of the sites. At all sites, elevated lead levels were measured after replacement on samples that represented the lead service line, and these elevated levels persisted for up to 3 days after replacement, even at sites where the entire lead service line had been replaced.

At sites where the entire lead service line was replaced, the calculated first-liter lead levels 2 months after replacement were lower than before replacement. At a site where a partial lead service line was replaced, no real improvement in total lead levels was measured even by 2 months after replacement, and the calculated 1-liter lead level 2 months after replacement was essentially the same as before replacement.

The mineralogy and chemistry of scale samples from the lead service lines were simple in structure and composition and showed little variation between sites. They were comprised of an upper layer of amorphous aluminum hydroxide with some iron oxyhydroxide and a lower layer comprised predominately of hydrocerussite with secondary cerussite. For sites where full lead service line replacement occurred, the amount of reduction in lead levels measured at the tap may have been related to the composition of the surface scale layer. More lead was released from scales that contained more non-lead components in the scale, possibly because of destabilization of the scale due to incorporation of these other components. This was supported by the PHREEQC modeling results which showed that the water was in equilibrium with a poorly crystalline aluminum hydroxide ($Al(OH)_3$ seen in XRD results). Crystalline iron oxide/hydroxide (FeOOH) was too highly supersaturated to be the controlling iron phase, which was more likely a totally amorphous iron (III) hydroxide ($Fe(OH)_3$, again, which was seen in SEM-EDS results). The water was strongly undersaturated with all lead minerals, including hydrocerussite. Therefore lead releases may not be controlled by equilibrium dissolution of the hydrocerussite component of the scale, but by some set of kinetic factors, such as the protective covering of aluminum-iron (Al-Fe) hydroxide on the surface of the scale.

BWSC

At BWSC, total lead levels measured in sequential samples collected at the tap from field study sites were low before lead service line replacement activities, with the exception of samples representative of the lead service line and the first 125 mL collected at the tap, indicating that both a portion of the premise piping and the lead service line were contributing to lead levels measured at the tap. The majority of lead measured was in the dissolved form before lead service line replacement, and by 1 and 2 months after replacement. For the first 3 days after replacement however, high particulate lead was measured at several sites.

Flushed samples exhibited low lead levels before replacement at all sites, but higher particulate lead was measured in flushed samples for 1, 2, and 3 days after replacement at several of the sites.

Calculated first-liter lead levels were very low at two sites, and there was essentially no difference between values measured before or after replacement. At the other two sites, calculated first-liter lead levels were substantially higher for the first 2 to 3 days after replacement, but by 2 months after replacement they were lower than values before replacement.

Both premise brass piping and lead service line piping were analyzed for scale. The brass pipe scales were dominated by copper minerals and the lead pipe scales were dominated by lead minerals. The brass pipes had appreciable zinc, calcium, iron, and silica in addition to copper, and also had small amounts of aluminum, manganese, and phosphorus. Barium also occurred in the surface scale. Layer 1 scales (the layer closest to the water) had larger amounts of these other elements, particularly iron, whereas Layer 2 was mostly copper. Scales on the lead pipe samples were dominated by lead, with high calcium, iron, and manganese in Layer 1. Phosphorus was low and vanadium was very low in scales on both lead and brass.

Framingham and MDC

Two sites were sampled at Framingham and one site at the MDC before and after the existing faucets were replaced with faucets manufactured using a non-leaded alloy. At Framingham, one of the sites had a partial lead service line in place and the other had a full lead service line. The site at the MDC had a copper service line. At both utilities, the majority of lead measured was in the dissolved form. At Framingham, the impact of the existing lead service lines at these sites was clearly indicated by the elevated lead levels measured from samples collected from the fifth, sixth, and seventh liters of water collected at the tap during sequential sampling at these sites.

At Framingham, two lead peaks were evident during sequential sampling at the site with a full lead service line, one associated with the premise piping and one associated with the lead service line. Total lead levels were elevated after faucet replacement but generally declined over time. Physical disturbance of the premise piping during the faucet replacement procedure, continued contributions from the existing lead service lines, and/or a lead source in the replacement faucet are the possible sources of lead in samples taken after faucet replacement. Flushed samples contained higher lead levels after faucet replacement at one site when compared to samples collected before replacement, and in some cases were greater than the action level. Faucet replacement had no impact on LCR compliance at these sites, which exhibited first-liter lead levels similar to levels measured prior to faucet replacement.

At the MDC, the highest lead levels measured before faucet replacement were from the initial 125-mL sample collected at the tap, implicating the faucet as a primary contributor to lead measured at the tap, however these lead levels were relatively low (6 to 7 μg/L). One week after faucet replacement, total lead levels were higher in the second 125-mL sample collected during sequential sampling when compared to levels measured before replacement, but were still below the action level of 15 μg/L. Total lead levels measured from flushed samples at Site MDC-1 were all less than 1 μg/L and calculated 1 liter lead level results at Site MDC-1 were all low, indicating no benefit from faucet replacement at this site.

The deposits on the interior of the faucets removed from the Framingham sites were usually observed to occur in patches surrounded by exposed brass. The scale was chemically homogeneous and the cold water supply was dominated by malachite and zinc oxide/carbonate with an underlayer of cuprite. The hot water supply was dominated by tenorite and the zinc oxide/carbonate. In generally, the zinc and lead contents of the scales were higher than the zinc and lead contents of the brass material, suggesting preferential dissolution of these two components which are then reprecipitated in the scale.

At the MDC, the scale was relatively continuous and was similar on both the copper supply line and the interior brass surfaces. It consisted of mostly amorphous or poorly crystalline phases with some cuprite.

Summary

In general, sequential tap monitoring before and after lead service line replacement found that lead levels measured from residential sites can be highly variable, and dependent on the specific physical configuration of each site. For each utility that participated in the field study portion of the project, water quality measured at sites where lead sources were replaced were relatively consistent, however total lead levels measured from stagnation samples could still be variable from site to site. Conducting sequential sampling at each site and graphing the lead level results from each sample provided a visual snapshot of which areas of the system released lead (faucet, premise piping, lead service line), and these results provided information to estimate the relative contribution of various lead sources at each site. As would be expected, evaluation of lead levels before and after lead source replacement found that, in general, sites with higher lead levels prior to replacement experienced more improvement in first-liter lead levels by 1 or 2 months after replacement. In many cases, however, replacement of the lead service lines caused high particulate lead to be measured at the tap in the first 3 days after replacement.

DCWASA Historical Data

DCWASA conducted lead profile sampling at numerous sites within their service area from December 2004 through January 2007. All sites contained lead service lines. These profiles were made available for this study, along with information on which samples corresponded to premise piping versus service piping were provided. Results from these profiles can be found in Appendix H on the CDROM accompanying this report. Lead level results from profiles completed in 2003 and 2004, prior to implementation of orthophosphate treatment, clearly indicated the presence of lead service lines in sequential samples collected at the tap, and also the overall improvement in lead levels with orthophosphate treatment. Average lead levels were lower after use of orthophosphate, both for samples representing premise piping and for samples representing service piping. Prior to use of orthophosphate, the average lead concentration from service piping was more than twice the concentration from premise piping. After orthophosphate treatment, the average lead concentration from premise and service piping was similar.

CHAPTER 3
CONTRIBUTION OF LEAD SOURCES TO LEAD AT THE TAP

This chapter summarizes the relative contributions of lead service lines, meters, premise piping, and faucets to lead levels measured at the tap during sequential sampling; how these contributions changed with lead source replacement; and the affect that lead sources may have on LCR compliance. The lead source contributions discussed in this chapter represent actual standing lead levels measured from pilot studies and taps under the specific water qualities, materials, and site characteristics evaluated in these studies. While these values cannot be translated directly to another utility's evaluation of the amount of lead that might be released from lead sources in their system, they do provide 1) an example of how to determine which materials may be contributing to lead levels measured at the tap, 2) an indication of typical lead concentrations, lead mass, and relative percent contributions from various lead sources that may be applicable to other systems with similar water quality and materials characteristics, and 3) how replacement of lead sources may affect lead levels at the tap.

The following sections present the methodology used in these evaluations, the results of lead source contribution evaluations which are categorized by major lead source [lead service lines, meters, premise materials (including the faucet)], the effect of lead source replacement on lead levels at the tap, and a discussion of the potential affects that these lead sources may have on LCR compliance. Finally, an assessment of lead service line pipe cutting techniques is presented, and a summary of how these techniques may affect lead levels measured at the tap is provided.

METHODOLOGY

Relative Lead Source Contributions

Contributions of each of the major lead sources (service lines, meters, premise materials, and faucets) were evaluated based on information from case studies, pilot evaluations, and field data collection completed for this project. Historical case studies and pilot studies completed for this project measured lead concentrations directly from the faucets, meters, and lead pipes installed in pilot rigs, and the mass of lead from each component or pipe was calculated using the concentration measured and the volume of sample collected. Case studies are presented in Appendix B, and Appendix C presents a detailed discussion of these pilot studies.

Other historical case studies and field study sampling for this projected consisted of collecting sequential volumes of standing water from the tap and analyzing each sample for total and dissolved lead (see Appendix F for field study results). Surveys of the piping characteristics from the faucet to the service connection (material, diameter, approximate length) were completed at each site and used to categorize each sample collected as representing either the faucet, premise material (and in some cases the combined faucet and premise material), lead service line, or main. Using these profile results, the total mass of lead and average lead concentrations measured during sequential sampling were calculated for each lead source. Dilution and mixing during sample collection made it difficult to quantify exact contributions from each source using this sampling protocol, particularly for those sources farther away from the tap. However the results do provide an indication of where the major lead sources occurred within these premise piping systems, the relative extent of lead release from theses various sources, and a comparison of the contributions from multiple sources. Figure 3.1 displays a schematic illustrating an example of this approach.

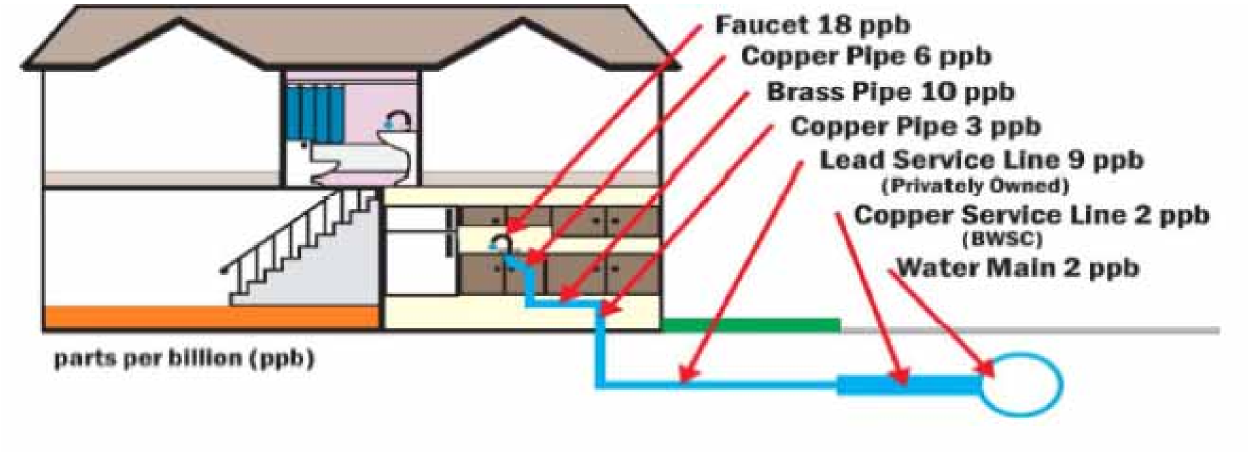

Figure 3.1 Breakdown of relative lead level concentrations in one home (MWRA 2005)

Effect of Lead Source Replacement on Lead Levels at the Tap

The effect of lead source replacement on lead levels at the tap was evaluated by summarizing 1) specific case studies from DCWASA and LWC where extensive evaluations of lead service line replacement have been conducted, and 2) field study data collected for this project at sites where lead service lines were replaced and sites where faucets were replaced to determine reductions in mass of lead measured at the tap during sequential sampling and differences in first-liter standing lead levels measured at the tap after the lead source was replaced. These information sources were also used to document lead spikes experienced after a replacement was made.

Pipe Cutting Evaluation

An evaluation of various pipe cutting techniques was completed to assess the effect these techniques may have on lead levels measured at the tap and the occurrence of lead spikes measured after replacement of a lead service line. Sequential 1-liter samples were collected at the tap before and for 3 days after partial lead service line replacement and analyzed for total and dissolved lead. A site survey was completed at each location to determine the length and diameter of premise piping and service material. The differences in the total mass of lead measured at the tap before and 3 days after replacement were calculated for each site and results from sites where a hacksaw was used to cut the lead service lines were compared to sites where a disc cutter was used.

RELATIVE LEAD SOURCE CONTRIBUTIONS

Lead Service Lines

Lead service lines have historically been considered to be one of the primary sources of lead measured at the tap (USEPA 1991a; AwwaRF 1990). Studies completed by DCWASA (Giani et al. 2004) utilized ‘profile monitoring’, where sequential samples were collected at the tap after a 6-hour stagnation period and analyzed for lead. Lead level results from these profiles provided information on which lead sources may be contributing the lead levels measured at the tap (see Appendix B for case study).

DCWASA has continued to conduct lead profile sampling at numerous locations throughout their system to assess lead levels at the tap. Results of lead profile sampling conducted at ~30 different sites in the DCWASA distribution system from 2003 through 2007 were obtained for this study (Appendix H), and this data, along with results of sequential sampling completed at residential sites from five utilities (Madison, Wis.; DCWASA, Toronto, Ontario; Boston, Mass. and Framingham, Mass.) provided information with which to assess relative contributions of lead service lines to lead levels at the tap. In addition, a pilot evaluation which incorporated excavated lead service lines was completed by the Washington Aqueduct in 2006, and these results are also summarized.

The pilot study conducted by Washington Aqueduct utilized excavated lead service line piping to evaluate treatment effects on lead release. Average lead concentrations from the loops ranged from ~4 µg/L to 15.5 µg/L. Orthophosphate treatment was evaluated in several pilot study pipe racks, along with various disinfection schemes (high and low chloramines, switching between chloramines and free chlorine). The orthophosphate inhibitor effectively reduced lead from lead service line piping to levels at or below 10 µg/L in the pipe rig. High particulate lead was measured in racks using orthophosphate under higher chloramine conditions (Racks 2 and 6), whereas the rack with no phosphate inhibitor (Rack 4) had a higher percentage of dissolved lead than in racks with an inhibitor (see Appendix C for a more detailed discussion of the Washington Aqueduct pilot study).

The historical DCWASA profiles were generated by collecting sequential 1-liter samples at the tap after a 6- to 8-hour stagnation period. Each site contained a lead service line and at each site, information on which samples corresponded to premise piping versus service piping were provided. There were a wide range of lead concentrations and calculated lead masses from the lead service line samples from these profiles, and the average amount of lead from samples representing the service line was dependent on treated water quality conditions. For these sites, the average lead concentrations were 86 percent lower and the average lead mass measured at the tap during sequential sampling was 82 percent lower from samples representative of the lead service line after orthophosphate treatment was implemented when compared to averages calculated before treatment.

Profile sampling was also conducted at 19 field study sites for this project. Sites were sampled prior to lead source replacement, providing typical lead concentrations measured from service lines under a variety of water quality conditions and site characteristics. The lead concentrations measured from samples representative of lead service lines exhibited a wide range of values within each utility, with the widest range seen at Madison (4 µg/L – 114 µg/L) (see Appendix F for a more detailed description of these studies). The total mass of lead calculated from samples representative of lead service lines at these utilities also exhibited a wide variation

(9 ug – 343 ug). The average percent contribution of lead service line samples to total mass measured at the tap during sequential sampling for these profiles was relatively consistent however, ranging from 48 to 51 percent.

Table 3.1 lists the average lead concentrations, total mass, and percent contribution of lead service line samples for the profiles at DCWASA, and the field studies where samples representative of the lead service lines were collected.

Table 3.1
Average lead contributions from lead service line studies

Study	Average Pb Concentration from Lead Service Line Samples, µg/L (range)	Average Pb Mass from Lead Service Line Samples, ug (range)	Average % Contribution of Lead Service Line to Total Lead Mass at the Tap (from sequential sampling only)	Average Lead Service Line Volume, L (range)
DCWASA Profiles (2003 – 2007)				
No PO_4	58 (1-250)	250 (4-612)	64%	6.5 (4-10)
PO_4	8.4(0-34)	46 (0-144)	54%	7.1 (4-10)
Field Studies				
Madison	46 (4-114)	139 (11-343)	49%	3.3 (2.9 – 3.7)
DCWASA	12 (4-18)	55 (19-86)	57%	4.7 (2.7 – 6.5)
BWSC	13 (4-22)	31 (9-67)	48%	2.2 (1.8 – 2.7)
Toronto	14 (9-20)	44 (18-80)	48%	3.4 (1.1 – 11.1)
Framingham	27 (25-28)	110 (51-169)	51%	3.9 (1.8 – 5.9)

Meters

Meters are generally made from copper alloy materials (brass or bronze) that contain lead at percentages ranging from 1.5 to 8.0 percent, however there are also in-line components available that are made using alloys with no lead added, i.e., that contain less than 0.25 percent lead. The capacity for leaded brass alloys to contribute lead to the water has been established from several studies (Samuels and Meranger 1984; Neff et al. 1987; Schock and Neff 1988; Gardels and Sorg 1989, Paige and Covino 1992; Lytle and Schock 1996; Kimbrough 2001; Nielson 1975; Nielson 1983; Birden et al. 1985; Maas et al. 1997; Maas and Patch 1999). Results generally indicated that component parts made from higher lead content alloys released higher lead levels than component parts made from lower lead content alloys, and that lead levels declined over time. For this study, a case study evaluation of lead release from meters completed by DCWASA, along with results from a pilot study of residential meters completed at SPU were used to estimate the relative contribution of meters to lead levels measured at the tap. At the six utilities where lead profile sampling took place, the sampling protocol did not specifically target the meter contribution (Appendix F). The stagnant water contained in the meter would have been included in 1-liter samples collected at either the beginning of the lead service line, or the end of the premise piping section. Therefore, no separate assessment of the relative contribution of the meter to lead levels measured at the tap could be completed for the field study utility data.

DCWASA conducted a study of the contribution of bronze meters to tap lead levels and found that chloraminated and chlorinated waters resulted in average levels of 58 μg/L and 110.5 μg/L respectively, in a 700-mL sample (the volume contained in each meter). These samples were collected after stagnation periods of 6 to 7 hours. The chloraminated water containing phosphate had an average lead level of 17 μg/L at stagnation times of 3.5 to 5.5 hours. Switching from the chloraminated water with phosphate to chloraminated water with no phosphate caused an immediate increase in lead levels measured from the meter. DCWASA also conducted sequential sampling at a site with a copper service line and a bronze meter. Results indicated that the premise piping was the major source of lead at this site rather than the meter. The disparity in these results when compared to the laboratory evaluation of meters was presumed to be from dilution and or the age of the meter at this site. Therefore, even though new meters can release lead into the water, dilution and mixing effects, the presence of aged meters in the system, and the small volumes contained in each meter may minimize their effect on lead levels at the tap (Appendix B).

Pilot testing at SPU evaluated ¾-inch residential meters, five of which were made from brass containing up to 8 percent lead and one which was made from a non-leaded alloy with ~.10 to .25 percent lead. The meters ranged in service age from new, never used units to one that had been in service for 40 continuous years. The new leaded brass meter was found to release significant amounts of lead initially, and after 7 months of simulated intermittent use, was still releasing approximately 7 μg lead in a composite 1,750-mL sample (4 μg/L). In comparison, the 4-year old and 19-year old meters by the same manufacturer released 2 μg lead or less (1 μg/L) in the same tests.

Table 3.2 contains a summary of the lead contributions from meters evaluated in these studies. The wide difference in average concentration of lead measured from meters in these two studies is likely due to the different surface areas exposed to water, the age and lead content of the meters evaluated, and/or water quality and testing conditions. These results indicate that the presence of meters with alloys containing lead in the premise system may contribute to lead levels that will eventually arrive at the tap. For smaller, residential size meters however, the contribution may be quite small, and dilution and mixing due to flowing conditions in the premise system will likely obscure the ability to detect the slug of lead, particularly in a 1-liter standing sample collected at the tap which is more likely to represent lead derived from the faucet and immediately adjoining piping. Utilities could possibly develop an upper limit meter contribution concentration based on lead release studies using their specific water quality and the type of meters typically installed in their system, however.

Premise Materials

Primary sources of lead contained in premise piping include brass faucets, leaded solder used to join copper piping, galvanized piping, and other brass fittings that may be installed. The following section summarizes lead source contributions from case, pilot, and field study results related to premise materials.

The Philadelphia Water Department (PWD) compared lead samples of different volumes (volumes collected were 1000 mL and 50 mL) taken from the same faucet to evaluate the effects of the sample collection volume on lead levels. They found that on average, the 1000-mL lead samples (faucet and premise piping) contained 60 μg/L of lead and the 50-mL samples (faucet) contained 365 μg/L lead (Burlingame, 2003). Another study of 25 homes that were at least 20 years old involved collecting a standing 125-mL followed by 1000-mL sample. The average lead levels from these samples were 3.5 μg/L (125-mL sample) and 4.3 μg/L (1000-mL sample) (AwwaRF 2004).

Table 3.2
Average lead contributions from meters

Study	Average Pb Concentration from Meter Samples μg/L	Average Pb Mass from Meters Samples, ug	Average Meter Volume, L
DCWASA Meter Study (all new meters) (Giani 2004)			
Chlorinated	110.5(1)	77.4	.7
Chloraminated	58(1)	40.6	.7
Chloraminated with PO_4	17(2)	11.9	.7
SPU Pilot Study (3)			
Meter 2 (19 years)	1	2	.21
Meter 3 (4years)	1	2	.19
Meter 5 (non-leaded)	< 1	1.5	.16
Meter 6 (New)	4	7	.18

(1) Average of 2 meters at 6 -7 hours stagnation
(2) Average of 2 meters at 3.5 – 5.5 hours stagnation
(3) Values from composite 1.75 L samples

Lead profile sampling conducted by DCWASA at residential sites provided information on relative contributions from the premise piping section at each site. As discussed previously, the DCWASA profiles were generated by collecting sequential 1-liter samples at the tap after a 6- to 8-hour stagnation period. Information on which samples corresponded to premise piping versus service piping were provided from each site. The average lead concentrations were 51 percent lower and the average lead mass was 64 percent lower from samples representative of the premise piping after orthophosphate treatment was implemented when compared to averages calculated before treatment.

Profile sampling conducted for this study at 19 field study sites prior to lead source replacement provided typical lead concentrations measured from faucets and/or premise piping. Initial 125-mL samples, followed by consecutive 125-mL, 250-mL, and 1-liter samples were collected at the tap. The initial 125-mL sample was presumed to represent the faucet and immediate connective piping, and site survey results were used to determine the sequential samples that represented the remaining premise piping. The average lead concentrations measured from the initial 125-mL samples (faucet and immediate connective piping) ranged from 6.0 μg/L to 13.7 μg/L and from samples representative of the premise piping, the range was 1.1 μg/L to 28 μg/L. The average mass of lead calculated from the faucets was 0.8 ug to 1.7 ug and the average mass calculated from samples representative of the premise piping varied from 3.4 ug to 125 ug. This wide range of values is likely due in part to the different premise volumes at each site (see Appendix F for a more detailed description of these studies).

At sites with lead service lines, the average percent contribution of premise samples to total mass measured at the tap during sequential sampling was relatively consistent, ranging from 21 to 37 percent of the total, as was the relative percent contribution from the faucets (0.7 to 2.6 percent). At one location with no lead service line (MDC), the relative contribution from the premise and faucet to total lead mass was higher (55 percent and 12 percent respectively). Tabular summaries of lead contributions from these studies are shown in Table 3.3 (premise piping) and Table 3.4 (faucets).

Main

The relative contributions of each source to the total mass of lead measured at the tap during sequential sampling must also take into account the mass of lead derived from samples that were representative of the water main. At some field study sites, the consecutive samples collected at the tap included one or more samples that would have contained water that had resided in the main. In some cases, these samples contained relatively high concentrations of lead, possibly from pick-up of lead from existing corrosion scale as it passed through the service and premise piping, or from mixing with other water as it moved through the system. While these samples likely do not represent a ‘lead source’, they do provide an indication of the mass of lead and relative percentage of lead measured at the tap that may have been due to continued release of lead (soluble and particulate) from the various lead sources between the main and the flowing tap. Table 3.5 summarizes the contributions from samples representative of the main from field sampling conducted for this project. The average percent contribution of lead from samples representing the main ranged from 7 to 16 percent of the total mass of lead measured at the faucet during sequential sampling. Samples were not collected directly from the main in this study; as such, it cannot be confirmed that water in the main had little or no lead. The assumption is that lead levels in the water from the main are very low and that lead entered the water from service lines, premise piping, and end use components. The important finding is that lead release and uptake does occur in flowing water after a stagnation period, albeit at much lower levels than in standing water.

Table 3.3
Average lead contributions from premise piping

Study	Average Pb Concentration from Premise Samples μg/L (range)	Average Pb Mass from Premise Samples, ug (range)	Average % Contribution of Premise Piping to Total Lead Mass at the Tap (from sequential sampling only)	Average Volume, L (range)
Philadelphia case study				
Faucet and premise	60	60	-	1
Premise	4.3	4.3	-	1
Seattle Public Schools				
Flex connector	15*	0.5	-	.033
Brass elbow connector	200*	0.6	-	.003
Brass shut-off valve	100*	0.2	-	.002
DCWASA Profiles (2003-2007)				
Faucet and premise (No PO_4)	20.7 (2.3-57)	79 (12 – 167))	31%	3.7 (2-6.0)
Faucet and premise (PO_4)	10.1 (0-50)	28 (1 – 106)	40%	3.2 (2-6.0)
Field Studies				
Madison	28 (3-70)	125 (7-342)	38%	4.1 (3.2-5.1)
DCWASA	8 (5-10)	32 (15-43)	37%	4.3 (3.0-5.4)
BWSC	6 (5-7)	19 (13-29)	38%	3 (0.9-4.9)
Toronto	8(4-11)	26 (17-44)	29%	3.5 (2.9-4.1)
Framingham	18 (14-22)	41 (39-43)	21%	3.5 (2.9-4.1)
MDC	1.1	3.4	55%	4.4

* Concentrations proportional to a 250 mL samples are: flex connector (3.75 μg/L), brass elbow connector (50 μg/L), brass shut-off valve (25 μg/L).

Table 3.4
Average lead contributions from faucets

Study	Average Pb Concentration from Faucet Samples µg/L	Average Pb Mass from Faucet Samples, ug	Average % Contribution of Faucets to Total Lead Mass at the Tap (from sequential sampling only)	Average Volume, L (range)
Philadelphia Case Study	365	18.3	-	0.05
	3.5	.44	-	0.125
Portland Faucet Study(1)				
Faucet 1 (high)	3.7	3.7	-	1
Faucet 2 (high duplicate)	1.7	1.7	-	1
Faucet 3 (low)	2.7	2.7	-	1
Faucet 4 (non-leaded)	3.0	3.0	-	1
Faucet 5 (medium)	2.7	2.7	-	1
Faucet 6 (CA Prop 65)	2.0	2.0	-	1
Field Studies[2]				
Madison	13.7 (4.4-24.7)	1.7 (.6-3.0)	1.2%	.125
DCWASA	9.3 (5.3-15)	1.2 (.7-1.9)	1.3%	.125
BWSC	9.5 (2.7-17.9)	1.2 (.3-2.2)	2.6%	.125
Toronto	11.6 (6.4-15.8)	1.5 (.8-2.0)	1.7%	.125
Framingham	11.7 (4.1-19.2)	1.5(.5-2.4)	0.7%	.125
MDC	6.0	.8	12%	.125

[1] Average of composite 1 liter samples collected after 6 hour stagnation on 10/06, 5/06, and 11/06

[2] All samples were 125 mL

Summary

Tables 3.6 through 3.8 contain summaries of the average lead concentrations, average mass, and relative percent contribution from each of the major lead sources (faucet, premise, lead service line) as identified from studies that completed sequential sampling at the tap. These results provide an indication of typical amounts of lead that may be measured at the tap in water collected at residential sites after a 6-hour stagnation period. The results from these samples would be influenced by the amount of lead that may have been in the water at the beginning of the stagnation period, lead release during stagnation, and mixing and dilution effects as the water flowed during sampling. Because of site specific conditions (materials, volumes, water quality), there is a wide range of lead concentrations and lead mass measured from different parts of the service and premise piping at individual sites. However, the relative percent contributions from the various lead sources to total lead measured at the tap during sequential sampling was somewhat consistent. Lead service lines contributed an average of ~50 to 75 percent of the total lead mass measured at the tap, compared to ~20 to35 percent attributed to the premise piping and ~1 to 3 percent from the faucet. At the site with no lead service line, the faucet and premise contributed a greater percentage of lead mass to the total mass of lead measured at the tap (~12 percent and 55 percent respectively). Main samples percentages ranged from ~3 to 15 percent.

Table 3.5
Average lead contributions from samples representative of the main

Study	Average Pb Concentration from Main Samples µg/L (range)	Average Pb Mass from Main Samples, ug (range)	Average % Contribution of Main Samples to Total Lead Mass Measured at the Tap	Average Volume of Main Samples, L
DCWASA Profiles (2003 – 2007)				
No PO_4	15.3 (0.6 - 195)	99.5 (4-493)	7%	1
PO_4	3.1 (0 – 17.5)	16.4 (0-59)	6%	1
Field Studies				
Madison	37.6 (2.2-92)	38.3 (4.4-92)	16%	1.3
DCWASA	3.4 (2.2-4.5)	9 (4-14)	10%	1.7
BWSC	4.4 (2.6-7.1)	6.2 (3.3-9.3)	12%	1.5
Toronto	12.1 (11.2-13.5)	12.1 (11.2-13.5)	17%	1
Framingham	15.9	15.9	7%	1
MDC	1	1	16%	1

Table 3.9 lists the average lead concentration, and average lead mass identified from pilot studies of faucets, meters, and lead service lines. These results provide an indication of the amount of lead that might release from individual lead sources after a 6-hour stagnation period. In these studies, samples were drawn directly from the faucet, meter, or lead service line piping so mixing and dilution would not affect the lead levels measured. The Portland pilot study indicated that the average faucet contributions throughout the study ranged from 1.7 to 3 ug, similar to lead mass measured from samples representing the faucet during sequential sampling

at the tap. The average mass of lead measured from the ¾-inch residential meters used in the SPU meter study was 2 to 7 ug, with new meters releasing more lead than older meters. This lead mass from the meter would be included in the mass of lead measured from samples representing either the premise piping or the lead service line in sequential samples measured at the tap. In comparison to lead mass values measured during sequential sampling, this contribution is relatively small. Also, depending on the location of the meter, mixing and dilution would affect this slug of lead and minimize its contribution to lead levels measured at the tap.

Figure 3.2 presents a visual summary of the range of relative percent contributions from each of the major lead sources, based on the summary tables in this section. While these ranges are not absolute, and are based solely on the data evaluated for this project, they do provide information with which to draw some general conclusions about the relative contributions of various lead sources to total lead levels measured at the tap during sequential sampling after 6-hour stagnation period. First, when full lead service lines are present at a site, they are major contributors to lead levels measured at the tap and generally contribute the largest mass of lead measured at the tap during sequential sampling. Premise piping can also be a large contributor, but is generally less than the lead service line contribution. Faucets and meters are minor contributors to total mass, given the smaller volumes when compared to other lead sources. Lead measured from samples representative of locations where there was no lead source (from samples representing copper service lines and/or the main) indicate that lead can be picked up as the water flows through areas containing a lead source on the way to the tap. This could be due to erosion, scour, rapid solubilization of lead, and/or mixing. This pickup of lead in flowing samples also makes it difficult to characterize lead derived uniquely from specific sources, particularly sources that are further away from the tap.

Table 3.6
Summary of average concentrations of lead from each source during sequential sampling

	Average Concentration of Lead from each Source , μg/L			
	Faucet	**Premise**	**Service Line**	**Main**
Philadelphia	365(1)	-	-	-
Philadelphia	3.5	4.3	-	-
DCWASA Profiles (2003-2007)				
Faucet and premise (No PO_4)	-	20.7(2)	58	15.3
Faucet and premise (PO_4)	-	10.1(2)	8.4	3.1
Madison	13.7	28	46	38
DCWASA	9.3	8	12	3
BWSC	9.5	6	13	4
Toronto	11.6	8	14	12
Framingham	11.7	18	27	16
MDC(3)	6.0	1.1	<1.0	1

(1) 50 mL sample. All other faucet volumes were 125 mL

(2) Includes the faucet

(3) Copper service line

Table 3.7
Summary of average mass of lead from each source during sequential sampling

	Average Mass of Lead from each Source , ug			
	Faucet	**Premise**	**Service Line**	**Main**
DCWASA Profiles				
No PO_4		79(1)	250	99.5
PO_4		28(1)	46	16.4
Madison	1.7	125	139	38
DCWASA	1.2	32	55	9
BWSC	1.2	19	31	6
Toronto	1.4	26	44	12
Framingham	1.5	41	110	16
MDC	0.8	3.4	1 (2)	1

(1) Faucet and premise

(2) Although the service was copper, service line samples were reported to have lead at the detection level (1.0 μg/L), and this level was used in analysis

Table 3.8
Summary of relative % lead contributions from various lead sources as percentage of total mass measured during sequential sampling

Utility	**Faucet**	**Premise**	**Service**	**Main(1)**
DCWASA Profiles				
No PO_4		31%	64%	7%
PO_4		40%	54%	6%
Madison	1%	37%	49%	16%
DCWASA	1%	37%	57%	10%
BWSC	3%	38%	48%	12%
Toronto	2%	29%	57%	17%
Framingham	0.7%	21%	76%	7%
MDC (2)	12%	55%	16% (3)	16%

(1) Lead concentrations in samples representative of the main were likely due to mixing and pick-up of lead from other service and premise sources.

(2) Entire service was copper. Other utility sites contained lead service lines.

(3) Copper service, however service line samples had lead reported at the detection level (1.0 μg/L) which was used in analyses.

Table 3.9
Summary of average lead concentrations and lead mass from pilot studies

	Average Lead Concentration, µg/L	Average Lead Mass, ug	Sample Volume, mL
Portland Faucet Study(1)			
Faucet 1 (high)	3.7	3.7	1
Faucet 2 (high duplicate)	1.7	1.7	1
Faucet 3 (low)	2.7	2.7	1
Faucet 4 (non-leaded)	3.0	3.0	1
Faucet 5 (medium)	2.7	2.7	1
Faucet 6 (CA Prop 65)	2.0	2.0	1
Seattle Meter Study			
Meter 2 (19 years, leaded)	1 µg/L	2	1.75
Meter 3 (4 years, leaded)	1 µg/L	2	1.75
Meter 5 (new, non-leaded)	< 1 µg/L	1.5	1.75
Meter 6 (new, leaded)	4 µg/L	7	1.75
Washington Aqueduct Pipe Loop Study			
No PO_4 (Rack 4)	8.3	9.1	1.1
PO_4 (Racks 1-3 and 5-7)	3.8 - 15.5	4.2 – 17.1	1.1

[1] Concentrations are an average of 1-liter samples collected after 6 hour stagnation on10/06, 5/06, and 11/06

EFFECT OF LEAD SOURCE REPLACEMENT ON LEAD LEVELS AT THE TAP

Lead Service Line Replacement

When a lead service line is replaced, historical literature and case study experience indicates that elevated lead levels can occur for a period of time. The extent of these elevated lead levels, and the length of time that elevated lead levels may be measured, are of particular interest when making decisions about implementing a lead service line replacement program. In addition, the form of lead that is measured (particulate versus dissolved) provides information on the possible causative factors contributing to the lead release (physical versus chemical). An evaluation of the effect of lead service line replacement on lead levels measured at the tap was completed by summarizing case study information and the results of sequential sampling completed at the field study utilities for this project.

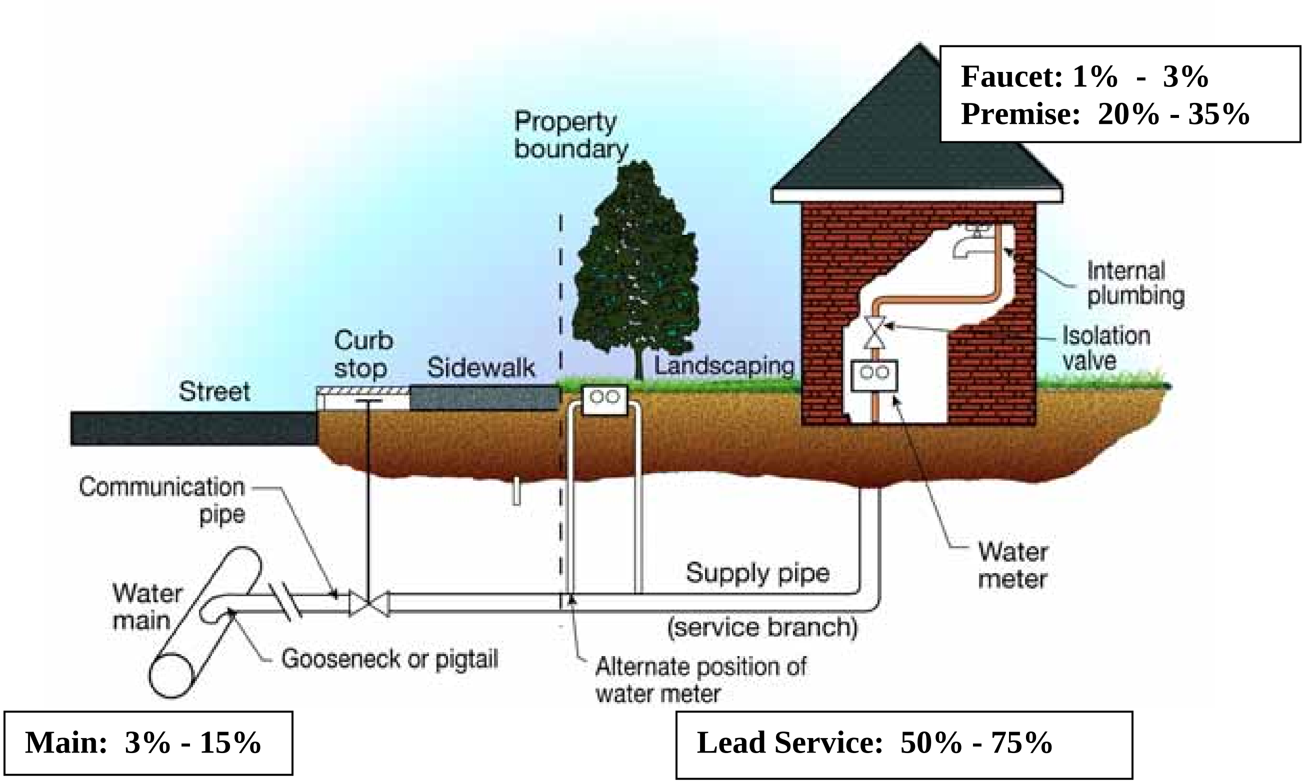

Figure 3.2 Estimated relative percent contributions from various lead sources for sites with lead service lines.

Case Studies of Lead Service Line Replacement.

Specific case studies related to lead service line replacement were completed at DCWASA and the LWC (Appendix B). At DCWASA, sampling results at partial lead service line replacement sites indicated high lead levels (>1000 μg/L), which were attributed to lead particles derived from disturbance and exposure of the 'cut' joint. DCWASA conducted specific evaluations at seven residences before and after partial lead service line replacement to evaluate the duration of temporary high lead levels. Samples were collected before replacement, after cutting and flushing, and for up to 2 weeks after replacement. Lead levels were higher overall before replacement when compared to lead levels after replacement, and all samples before replacement were above 15 μg/L. After partial replacement, only samples representative of the remaining lead service lines were greater than 15 μg/L. The average lead level of samples representative of the lead service lines was 60 μg/L before replacement and 17 μg/L after partial replacement. There was no significant change in lead levels during the subsequent 2 weeks of sampling. The study determined that flushing immediately after replacement of a lead service line reduced tap lead levels caused by construction and was likely the most important factor in reducing lead levels following partial lead service line replacement. After completion of this study, DCWASA implemented flushing requirements for lead service line replacement (Wujek 2004) as follows:

- The service must be flushed at an external hose bib for at least 15 minutes; or
- The customer must conduct appropriate flushing inside for 15 minutes.

LWC implemented a lead service line replacement program in association with their main replacement program in the 1980s. LWC's lead service line replacement program addressed the utility owned portion of the service line from the main to the customer property line including the meter. In 1994, LWC conducted water quality monitoring immediately after a lead service line renewal of their part of the service and found that elevated lead levels were present (Coombs 2005). The lead monitoring results included lead testing on samples taken immediately after renewal for a period of 60 minutes. Lead testing was performed on filtered and unfiltered samples, from both forward (normal) flushing into the residence, and backflushing (from residence to meter). Forward flushed required over 15 minutes of flushing to reduce the total lead concentration below the action level, and over 35 minutes were required to reduce the lead concentration of total lead levels in samples that were backflushed.

Based on these and other sampling and test results, the current LWC procedure is to continue flushing (forward – from meter to residence) for a minimum of 60 minutes immediately following a lead service line renewal. In 2005, LWC performed water sampling at four homes where multiple samples of water were obtained before, during, and after the lead service line renewal of their part of the service. At two sites, total lead levels started to rise 50 minutes after the lead service line replacement. The dissolved lead levels from the same time frame contained low lead concentrations (0.9 μg/L and <0.5 μg/L for the 60-minute sample), and it was assumed that the high total lead content resulted from particles dislodged from flow changes inside the residence or from disturbances resulting from nearby lead service line replacement work. The lead concentrations taken as "first-draw" samples after the lead service line replacement of their part of the service were all less than 6 μg/L (total lead) at the four locations with one exception. More recent lead service line evaluations found that flushing for 3 minutes prior to taking the first draw sample after replacement tended to decrease the total lead content in almost all samples.

Historical studies at the Madison Water Utility have found that dissolved lead concentrations are lower after full lead service line replacement, but total lead concentration are erratic, and continue to be erratic for several years. Evaluation of the scale present on Madison lead service line pipes indicates the presence of lead compounds intermingled with manganese and iron scale layers. Destabilization of these manganese/iron deposits may have caused intermittent releases of microparticles resulting in elevated lead levels (Cantor 2006). A 1991 Cincinnati study found that high lead levels sometimes occurred following partial lead service line replacement, but after 9 months the lead levels decreased. In addition, the spiked lead levels often decreased with flushing of the plumbing systems (DeMarco 2004). In 1999, another Cincinnati study uncovered a lead spike after partial line changeovers. The spikes in lead concentration typically lasted 1 to 4 weeks. But even after 1 year of sampling, partial lead service line replacement did not show an improvement over keeping a complete line in place (Swertfeger et al. 2006).

Field Studies of Lead Service Line Replacement

Sequential sampling was completed at fourteen sites in Toronto, DCWASA, Boston, and Madison after the lead service line had been replaced as part of the field monitoring completed for this project (Appendix F). The consecutive samples were collected at the tap prior to lead service line replacement and then 1, 2, and 3 days, and 1 month and 2 months after lead service line replacement. Immediately after lead service line replacement, all the house faucets in the house were fully opened and flushed for 15 minutes to remove any lead particulates that had been released into the water during the replacement. The day after replacement, water was again flushed for 15 minutes prior to starting the 6-hour stagnation period. At the majority of sites, full lead service line replacement was completed, but two sites completed partial lead service line replacements that were sampled for up to 2 months.

At two utilities (Boston and Toronto) flushed samples were also collected at the tap on the day of replacement. The water was flushed for 15 minutes prior to collecting the 1-liter samples. At BWSC, lead levels measured just prior to the replacement were low (<4 µg/L); however, high particulate lead was measured in samples collected immediately after replacement and flushing at three of the four sites, with total lead levels up to 800 µg/L measured. In Toronto, lead levels measured on flushed samples the day of replacement were generally low both before and after the replacement and flushing, with the exception of one site where high particulate lead was measured (242 µg/L). Figure 3.3 presents an example of elevated lead levels measured on the day of replacement from flushed, 1-liter samples.

After the lead service lines were replaced, many sites registered high lead concentrations in sequential stagnation samples collected at the kitchen faucet for up to 3 days, for both partial and full replacements. These results were likely from disturbing existing service lines and indoor plumbing caused by the excavation, cutting, and replacement of the service. Some of the lead levels were extremely high and contained primarily particulate lead. Flushing for 15 minutes immediately after the replacement, and again the next day prior to the start of the stagnation period, did not adequately reduce these high lead levels. By 1 to 2 months after replacement, lead levels in all sequential samples collected at the tap were either lower than lead levels measured prior to replacement or essentially the same at sites where lead levels before replacement were already relatively low (see Appendix F for a summary of field monitoring activities).

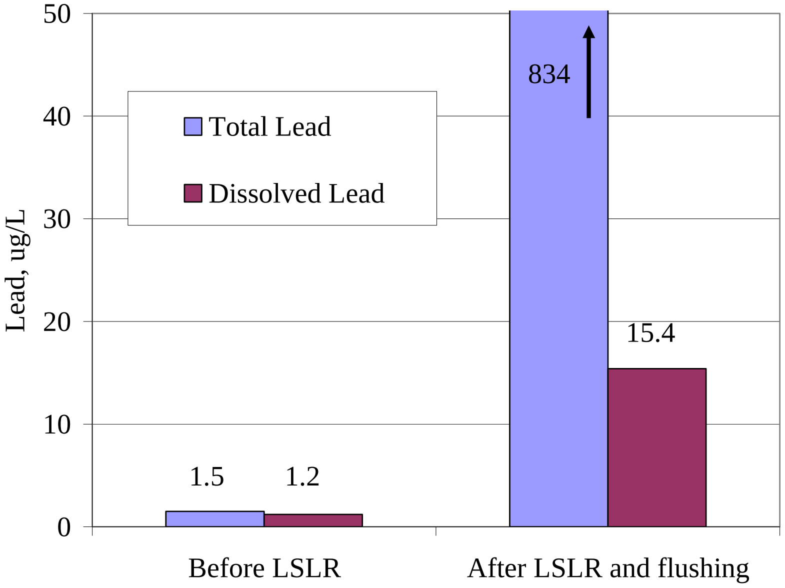

Figure 3.3 Example of lead levels measured from 1 Liter flushed samples on the day of replacement.

Table 3.10 presents a summary of the difference in total mass of lead at the tap measured from sequential samples collected before and after replacement (samples collected 1 or 2 months after), and the first-liter lead levels measured before and after replacement. The difference in total mass measured at the tap ranged from 2.6 ug to 544 ug. The site that had the lowest reduction in total mass (Site B-1) also had first-liter lead levels that were very low both before and after replacement (5.1 µg/L and 5.3 µg/L). At this site, replacing the entire lead service line did not improve an already low first-liter lead level. At the two sites where partial lead service line replacement took place, the reduction in total mass was also low (15 ug and 14 ug), and the first-liter lead levels measured at these sites after replacement were either higher than before replacement, or essentially the same (although at the site that was higher, these first liter lead levels were still below 10 µg/L). At the partial lead service line replacement site where first-liter lead levels were essentially the same before and after replacement (Site T-4), levels were 18.8 µg/L and 16 µg/L respectively. Partial lead service line replacement at this site did not improve LCR compliance by 2 months after the replacement. It's possible that a longer period of time might have been needed to reduce lead levels at sites where part of the service still contained lead piping. Based on case study experiences, a more rigorous flushing regime may also have helped reduce high particulate lead levels measured in the days after replacement.

Table 3.10
Difference in total mass and first-liter lead levels before and after lead service line replacement

Site1	type	Time After Replacement	Difference in Total Mass at Tap	1st Liter Lead Before, µg/L	1st Liter Lead After, µg/L	Difference in 1st Liter Lead Levels Before-After, µg/L
M-1	Full	2 months	412.4	10.4	5.3	5.0
M-2	Full	2 months	15.0	2.2	1.4	0.8
M-3	Full	2 months	142.8	12.2	1.7	10.8
M-4	Full	2 months	544.1	7.9	3.3	4.4
D-1	Full	1 month	48.9	8.8	13.0	-4.2
D-2	Full	1 month	115.0	12.0	2.4	9.6
D-3	**Partial**	**2 months**	**14.9**	**3.7**	**7.5**	**-3.8**
B-1	Full	2 months	27.6	7.1	1.3	5.8
B-2	Full	2 months	91.7	2.7	1.9	0.8
B-3	Full	2 months	2.6	5.1	5.3	-0.2
B-4	Full	2 months	38.4	8.5	4.8	3.7
T-1	Full	2 months	51.8	10.2	7.5	2.7
T-2	Full	2 months	35.3	5.6	1.6	4 .0
T-3(1)	Full	2 months	103.6	14.4	5.1	9.3
T-4	**Partial**	**2 months**	**14.0**	**18.8**	**16.0**	**2.8**

(1)Customer side was copper prior to replacement, so utility side was replaced for full LSLR
Partial replacement sites are in bold

For the remaining sites where the entire lead service line was replaced, first-liter lead levels were generally lower within 1 to 2 months after replacement, or the same after replacement at sites where the first-liter lead levels was already low before the replacement (i.e., ≤5 μg/L). One site (D-1) exhibited a reduction in total mass measured at the tap during sequential sampling, but the first-liter lead level was higher after full lead service line replacement (8.8 μg/L before and 13.0 μg/L after). At this site, the third sample volume collected at the tap (third 125-mL sample) before replacement had a lead level of 20 μg/L, indicating that there was a source of lead in the premise piping, just beyond the faucet. This may have been due to a brass fitting or flexible connector. Full lead service line replacement at this site did not improve the first-liter lead level; however, additional sampling would be needed to verify if there would be improvement over time. Figures 3.4 and 3.5 display the total lead mass measured from sequential samples and the first-liter lead levels measured before and after replacement at field study sites.

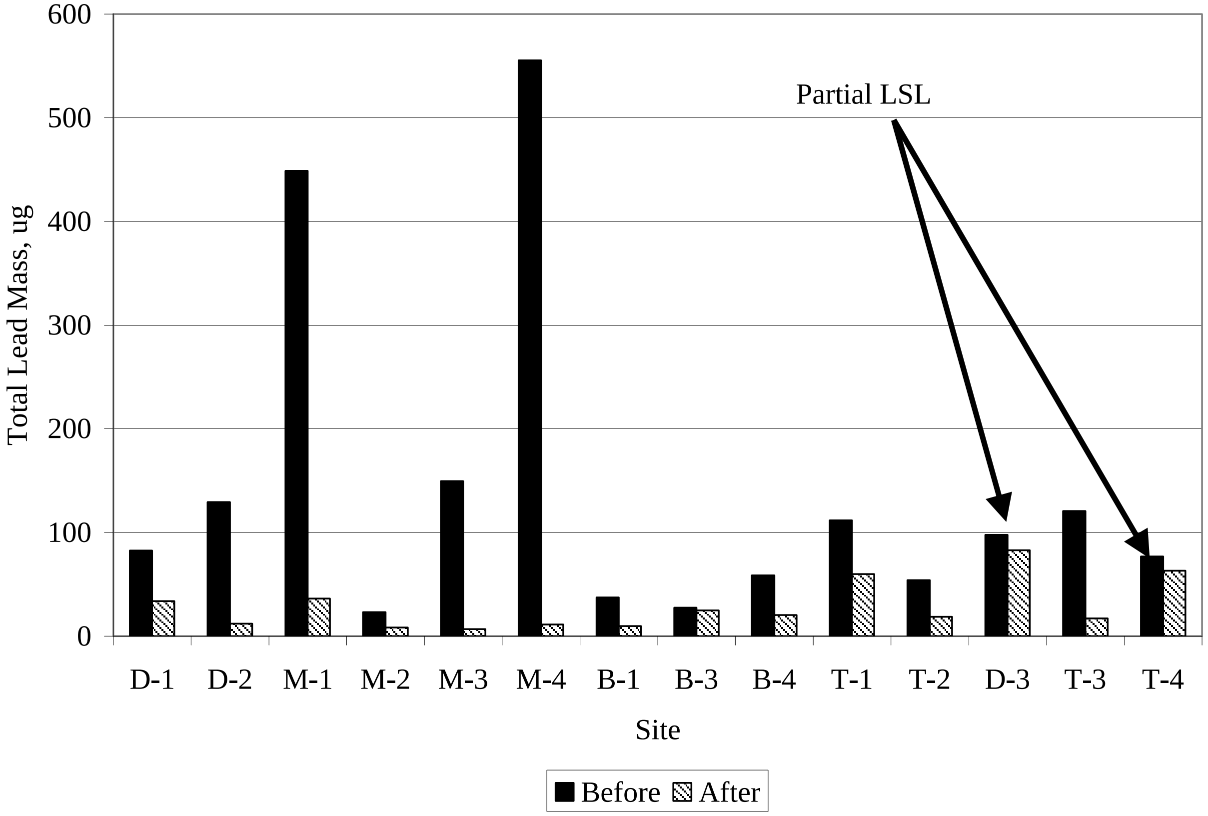

Figure 3.4 Total lead mass before and one or two months after LSL replacement

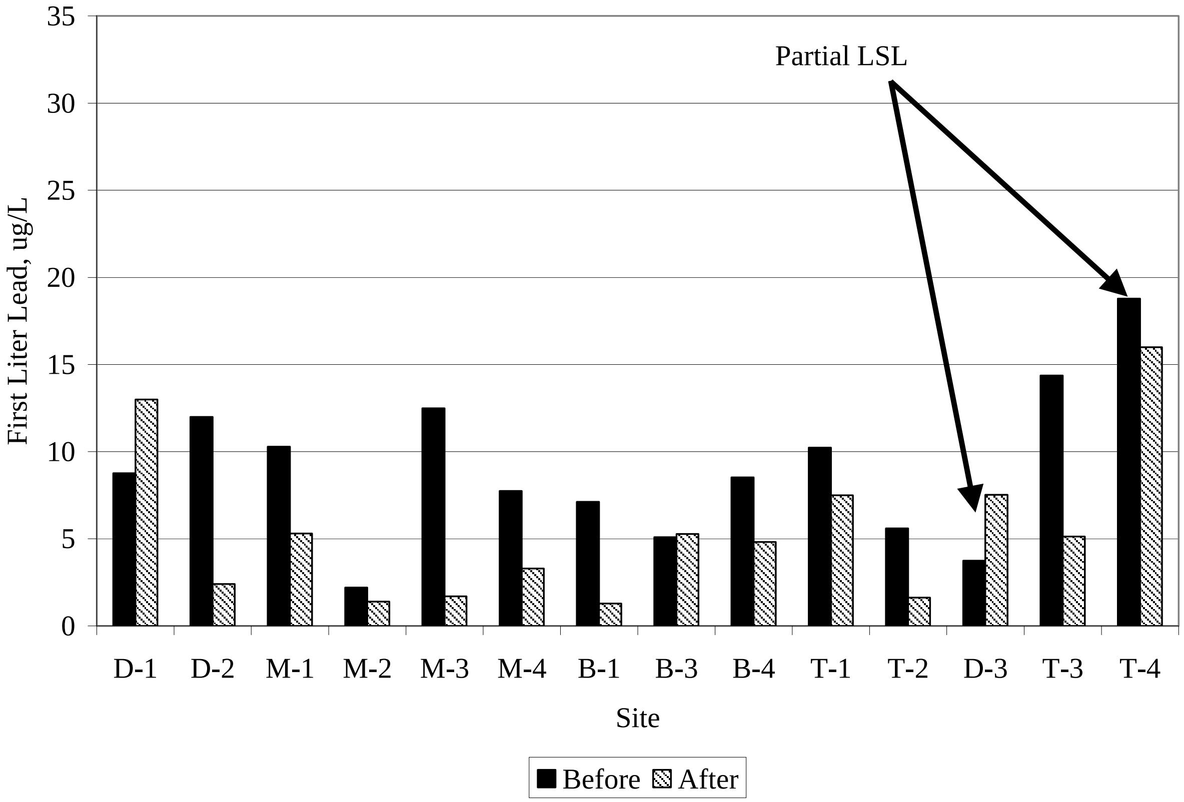

Figure 3.5 First-liter lead levels before and one or two months after LSL replacement

The mass of lead measured in sequential samples representing the faucet, premise piping, service, and main, and the relative percent contribution of these various lead sources to total mass of lead measured at the tap during sequential sampling, also changed after lead sources were removed. Table 3.11 summarizes the mass of lead measure from these various lead sources before and after lead service line replacement. The mass of lead measured in samples representative of the faucet, premise, service, and main were all reduced after full replacement of the lead service line. At the two sites where partial lead service line replacement occurred, the mass of lead from the faucet and premise were similar to the mass of lead measured before replacement, and the service line samples were slightly lower.

Table 3.11
Average mass of lead from each source before and 2 months after replacement of the lead service line, ug

	Faucet	Premise	Service		Main[2]
			Lead Service	Copper Service (2)	
Madison					
Before (Pb Service- 4 sites)	1.7	125	139	-	38
After Full LSLR (Cu service – 4 sites)	-	1 (1)	-	5	1
DCWASA					
Before (Pb service – 3 sites)	1.2	30	55	-	10
After Full LSLR (Cu service – 2 sites)	-	12 (1)	-	10	1
After Partial LSLR (Pb/Cu service – 1 site)	-	34 (1)	30	8	10
BWSC					
Before (Pb service – 4 sites)	1.2	19	31	-	6
After Full LSLR(Cu service - 4 sites)	0.3	8	-	6	2
Toronto					
Before (Pb service – 4 sites)	1.4	26	44	-	12
After Full LSLR (Cu service – 3 sites)	0.6	10	-	18	4
After Partial LSLR (Pb/Cu service – 1 site)	1.4	15	11	28	8

(1) Includes both faucet and premise

(2) Lead was measured in samples representing copper services and the main. Lead measured from samples representative of the copper service was likely a result of pick-up of lead from other sources.

Table 3.12 summarizes the relative percent contributions from the faucet, premise, service and main to total mass of lead measured at the tap. At sites where partial lead service line replacement took place, the relative percent contributions from the faucet did not change with replacement. The premise piping contribution represented a greater percentage of the total mass after the lead service line was replaced when compared to before replacement, particularly for sites where a full replacement was completed. Samples representative of the copper service line after full lead service line replacement still contributed a significant percentage of lead to the total mass measured at the tap, likely as a result of the pick-up of lead from other premise sources. At sites where a partial lead service line replacement was completed, the total percentage contribution from samples representative of both the remaining lead service line and the new copper service were essentially the same as the relative contribution from the full lead service line prior to replacement.

Faucet Replacement

While it has been established that brass alloys used to manufacture faucets can release lead into the water, and that faucets can contribute to lead levels at the tap, there is little historical literature or utility experience related to replacement of faucets in residences, and the effect that replacement may have on standing lead levels and LCR compliance. A study completed by the PWB found reductions in lead levels at the tap were greater than 30 percent at sites where the kitchen faucet was replaced with a non-metallic faucet (EES 1995), but evaluations of faucet replacement using a non-leaded alloy faucet have not been reported. Since the premise system is outside of utility jurisdiction, faucet replacement programs have often been established as incentive programs to encourage the public to replace their own faucet (San Francisco Case Study – Appendix B).

An evaluation of the effect of faucet replacement on lead levels measured at the tap was completed by summarizing the results of sequential sampling completed at three field study sites, where utilities replaced homeowner's faucets (see Appendix F for a detailed description). The faucets were replaced at two sites in Framingham (sites F-1, F-2) and one site at the Metropolitan District Commission in Hartford (MDC) (site H-1). Site F-1 contained a partial lead service line, Site F-2 contained a full lead service line, and Site H-1 had a copper service. Sequential samples were collected at the tap after a 6-hour stagnation period before the faucet was replaced, and then once per week for 4 weeks after the replacement. The first two samples collected were 125 mL, followed by three 250-mL samples to separate the faucet contribution from the adjoining premise piping. At all sites, the original faucets were replaced with a faucet manufactured with a non-leaded alloy.

Table 3.12
Comparison of relative percent contributions of various lead sources before and 2 months after replacement of lead service line

	Faucet	**Premise**	**Service**		**Main(2)**
			Lead Service	**Copper Service(2)**	
Madison					
Before (Pb Service- 4 sites)	1%	37%	49%	-	16%
After Full LSLR(Cu service – 4 sites)	-	64 %(1)	-	33%	3%
DCWASA					
Before (Pb service – 3 sites)	1%	36%	57%	-	10%
After Full LSLR (Cu service – 2 sites)	-	54%(1)	-	41%	5%
After Partial LSLR (Pb/Cu service – 1 site)	-	41%(1)	36%	10%	12%
BWSC					
Before (Pb service – 4 sites)	3%	37%	52%	-	12%
*After Full LSLR (Cu servic*e - *4 sites*)	2%	44%	-	36%	18%
Toronto					
Before (Pb service – 4 sites)	2%	29%	57%	-	11%
After Full LSLR (Cu service – 3 sites)	2%	35%	-	52%	11%
After Partial LSLR (Pb/Cu service – 1 site)	2%	23%	17%	44%	13%

(1) Includes both faucet and premise

(2) Lead was measured in samples representing copper services and the main. Lead measured from samples representative of the copper service was likely a result of pick-up of lead from other sources.

Table 3.13 and Figures 3.6 and 3.7 display the difference in the total mass of lead measured at the tap from the first five sequential samples, and the calculated first-liter lead levels before and 1 month after faucet replacement. With respect to LCR compliance, there was no improvement in calculated first-liter lead levels with replacement of the faucet and at sites F-2 and H-1, no improvement in total mass of lead measured at the tap in sequential samples. Figure 3.6 displays the mass of lead from the faucet (first 125-mL sample) and the premise piping (second through fifth samples) before and 1 month after faucet replacement. At Sites F-1 and F-2, the mass of lead from the faucet was higher 1 month after replacement when compared to the mass of lead from the faucet before replacement. At Site H-1, the mass of lead from the faucet was lower 1 month after replacement. At all three sites, the premise piping contributed the greatest mass of lead measured at the tap. Figure 3.7 presents first-liter lead levels before and 1 month after faucet replacement. There was no improvement in LCR compliance at any of the sites after the faucet was replaced.

Table 3.13
1st-liter lead levels measured from faucet replacement sites

Site1	Time after Replacement of Faucet	Difference in Total Mass at the Tap in Sequential Sampling (first five samples)	1st Liter Lead Before, µg/L	1st Liter Lead 4 Weeks After Faucet Replacement, µg/L
F-1	1 Month	0.2	10.6	10.4
F-2	1 Month	-6.2	25.8	31.9
H-1	1 Month	-1.1	2.1	3.6

Table 3.14 displays the relative percent contribution of the faucet (125 mL) and the premise piping (875 mL) to first-liter lead levels measured before and 1 month after faucet replacement. The relative percent contribution of the faucet (125 mL) was higher after the faucet was replaced at sites F-1 an F-2, and lower at Site H-1.

Table 3.14 displays a comparison in the mass and relative percent contributions of the faucet (first 125 mL) and premise piping (second 875 mL) to first-liter lead levels before and 1 month after replacing the faucets. The relative percent contribution of the faucet (first 125 mL) to the total mass of lead in the first liter from the tap increased after faucet replacement at the two sites where lead service lines were in place, and decreased at the site with a copper service. The relative percent contribution of the second 875 mL sample volume (premise) to total mass measured at the tap in the first liter increased after faucet replacement at the copper service site, and essentially remained the same at the two sites where lead service lines were in place.

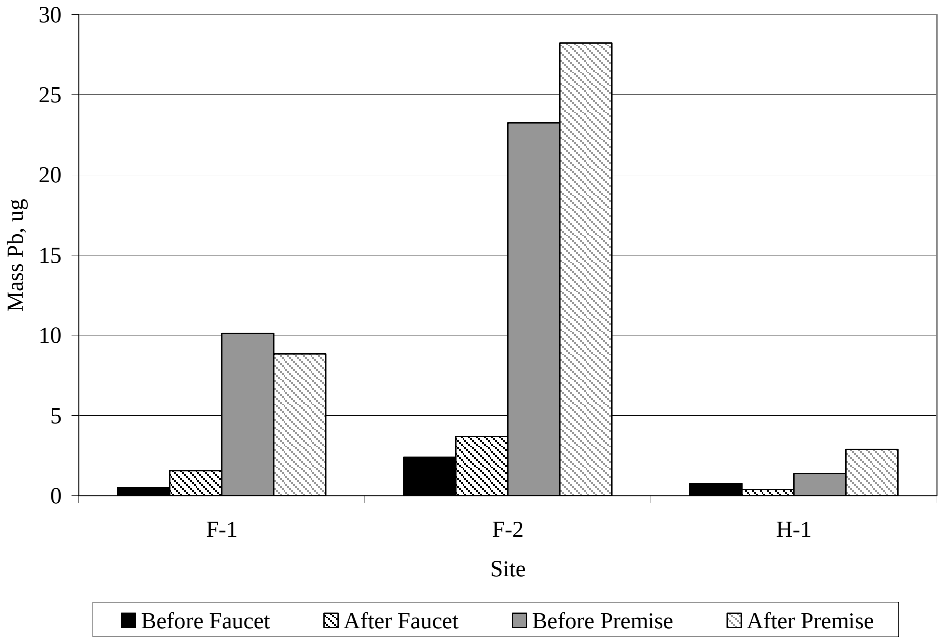

Figure 3.6 Mass of lead from faucet and premise piping before and four weeks after faucet replacement

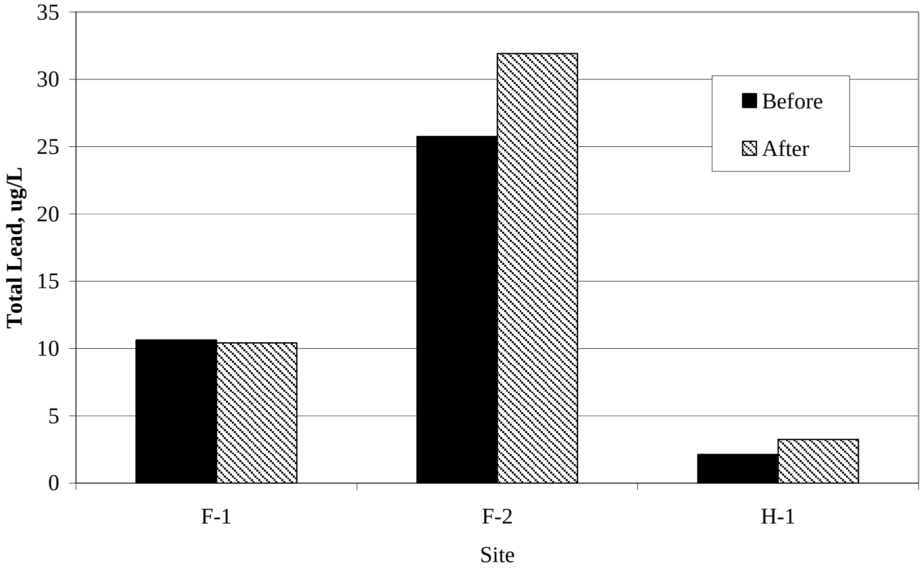

Figure 3.7 First-liter lead levels before and after faucet replacement

Table 3.14
Comparison of mass and relative percent contributions of faucet and premise piping to first-liter lead levels before and 1 month after replacement of faucet

Site		Faucet (first 125 mL)		Premise (second 875 mL)	
	Service Line Material	Mass of Lead, ug	Relative % Contribution to First-Liter Lead Mass	Mass of Lead, ug	Relative % Contribution to First-Liter Lead Mass
F-1					
Before	Pb/Cu service	0.5	5%	10.1	95%
1 month After	Pb/Cu service	1.6	15%	8.8	85%
F-2					
Before	Pb service	2.4	9%	23.4	91%
1 month After	Pb service	3.7	12%	28.2	88%
H-1					
Before	Cu Service	.75	35%	1.4	65%
1 month After	Cu Service	.38	12%	2.9	88%

It has generally been thought that older faucets may contribute less lead to the water than newer faucets made with leaded alloys. Since the replacement faucet used in this study was advertised as a non-leaded alloy, the source of lead in samples taken after faucet replacement could be from 1) parts of the replacement faucet that may have been manufactured with a leaded alloy that released lead, 2) pickup of lead from the lead service line or premise piping as water flowed through during sample collection, or 3) physical disturbance of the premise piping during the faucet replacement procedure and subsequent release of lead, although this may be unlikely as the majority of lead measured was in the dissolved form, and disturbance generally results in higher particulate lead release.

Summary

Based on the results of this study, lead levels at the tap are affected by replacement of the lead source. For lead service line replacement, physical disturbance to the system may result in high total lead levels measured at the tap in the short term (3 days), resulting in the presence of particulate lead in stagnation samples. Fully flushed samples may also exhibit high lead levels immediately after replacement. By 2 months after replacement, full lead service line replacement reduced the total mass of lead measured at the tap during sequential sampling as well as the calculated first-liter lead level measured at the tap, except in cases where lead levels were already low (~5 µg/L). For the two partial lead service line replacements that were completed, the total mass of lead and the calculated first-liter lead levels showed no difference 2 months after replacement when compared to levels measured before replacement.

Based on the results from the faucet replacement study, where the contribution of the faucet was relatively high prior to replacement (as in Site F-2), or low (site F-1 and Site H-1), replacing the faucet created no improvement in mass of lead derived from the faucet or the first-liter lead levels measured 1 month after the replacement. A relatively high mass of lead was measured from the faucet at Site F-2, where a full lead service line was in place. At Sites F-1 (partial LSL) and Site H-1 (copper service), the mass of lead from the faucet was much lower than at Site F-2.

In summary, while differences in water quality will strongly influence the amount of lead that releases from various lead sources, these results may indicate that the presence of a lead service line affects the amount of lead derived from the various lead sources in the system. It is hypothesized that over time, lead from the lead service line 'seeds' the system by moving through and being incorporated into the scales built up on lead surfaces of the premise piping (including the faucet), from which it can be released over time depending on physical and chemical conditions. This lead could be in the form of lead scale minerals, or dissolved lead species that interact with scale material, or lead that is sorbed or co-precipitated with other surface coating materials (such as iron, manganese, calcium or aluminum based minerals). Lead can be taken up into the water during stagnation and measured in standing samples collected at the tap, or picked up during flowing conditions. Removing the lead service line (whether full or partial replacement) may reduce the mass contribution from the faucet and premise piping over time as lead entrained in the scale is flushed from the system.

POTENTIAL EFFECT OF LEAD SOURCES ON LCR COMPLIANCE

LCR compliance sampling requires collection of standing first-liter samples collected at the tap. Previous sections have discussed the total mass of lead measured at the tap during sequential sampling to evaluate where lead may be coming from in the system, and how the lead mass derived from various lead sources and the relative percent contribution of the various sources may change after the lead service line or faucet are replaced. This section will discuss the effect that these lead sources may have on lead levels measured for LCR compliance, i.e., first-liter lead levels from kitchen taps after standing motionless for 6 hours.

As presented previously in Chapter 2, the contribution of the various lead sources in the system (faucet, premise, meter, service) to lead levels that may be measured at the tap during LCR compliance sampling is complicated by a number of site specific factors, which are summarized in Table 3.15. In addition to these factors, results from this study have identified other issues that further complicate the ability to determine the contribution of these sources to first-liter lead levels. These include lead service lines 'seeding' the premise system with lead, uptake of lead in background samples, uptake of lead in flowing water samples, and faucet variability, which are discussed in the sections below.

Lead Service Lines 'Seeding' the Premise System with Lead

Results from sequential sampling at field study sites indicate that after a full lead service line replacement, the mass of lead from samples representing the faucet, premise piping system, lead service line, and main were all decreased by 2 months after replacement. This would indicate that the presence of the lead service line caused higher lead masses to be measured from lead sources in the system than might have been measured if the site did not have a lead service line. Lead released from lead service lines over time, or even due to short term physical disturbance of the service during replacement or nearby construction, may migrate into the premise piping system and ‘seed’ the corrosion by-product scales present on the surface of the material. This lead may then be released from the corrosion scale into the water during stagnation or flowing conditions. Removing this original ‘source’ of lead by replacing the lead service line, may lower the contribution of lead from other lead sources as well, as this ‘seeded’ lead is ‘flushed’ from the system over time. The possibility of lead service lines ‘seeding’ the premise system may also help explain results at the case study at Madison where elevated lead levels were measured at sites for several years after the lead service line had been replaced. Therefore, when a lead service line is present, it is likely the controlling factor in both the total amount of lead measured at that site, the mass of lead contributed by individual lead sources, and how those sources contributed to compliance sampling results. While results from this study indicate that lead mass is reduced by 2 months after replacement, the length of time that may be needed for this ‘seeded’ lead to be removed from the premise system after the lead service line is removed is likely system and site specific.

Uptake of Lead in Background Samples

Results from case and field study sampling indicated that relatively high lead levels can be measured in what are considered background, flushed samples. In general, background samples measured during field sampling exhibited low lead levels, however there were instances where high particulate lead was measured (as high as 36 μg/L) (see Appendix F). High lead in flushed samples indicates that flowing water can pick up lead from lead sources in the system. Therefore, even after flushing for 15 minutes prior to the stagnation period (as was done in the field study portion of the project) there may still be elevated lead in the water. If this slug of lead is contained in the faucet and immediate premise piping prior to the start of LCR stagnation, then it would be additive to the lead released during the stagnation period, making it difficult to identify specific lead contributions from various sources.

Uptake of Lead in Flowing Samples after Stagnation

In addition, stagnation samples representative of copper service lines and the main during sequential sampling often exhibited higher lead levels than would be expected. These higher than expected lead levels could also be from uptake of lead as the water flows through the piping system. Uptake of lead in flowing water samples was also reported by DCWASA (case study) where four of five homes with lead service lines were sampled found that lead levels did not decrease to below the lead action level, even after the water had run for 20 minutes as part of collecting the lead profile sampling.

Faucet Variability

The contribution of faucets to lead measured in first-liter LCR compliance samples is also complicated by the variabilities in 1) faucet construction, 2) alloys used to make faucets, and 3) manufacturing process used to make the faucet. These factors can affect the release of lead from new faucets and the intermittent release of lead over time as discussed in results from the faucet pilot study (Appendix C).

Table 3.15
Factors affecting lead uptake and contribution of lead sources to LCR compliance samples

Lead Source	Factor Affecting Uptake of Lead from This Source
Lead Service Line	• Length and diameter of the lead service line (longer lengths and/or smaller diameters may result in higher lead levels) • Water quality conditions • Water use and hydraulic patterns • Disturbance from replacement (short term)
Meter	• Volume of water contained in meter, and surface area of meter exposed • Water quality conditions • Water use and hydraulic patterns
Premise	• Lead Solder: – Number of joints – Age of the solder – Workmanship of the soldering – Surface area of soldered joints exposed to water – Water quality conditions – Water use and hydraulic patterns • Galvanized pipe: – Length and diameter of piping – Surface area exposed to water – Water Quality Conditions • Presence of lead service • Disturbance from replacement of lead service
Faucet	• Surface area of faucet exposed to water • Physical configuration of the faucet • Manufacturing process • Water quality conditions • Flow conditions • Lead from presence of lead service, seeding and uptake of lead from scales

Given these complicating factors, the contribution of the various lead sources (faucet, premise piping, meter, and lead service line) to first-liter lead levels will be site specific, and will need to be evaluated on a case-by-case basis. Tables 3.16 and 3.17 present summaries of results for the first 125-mL sample and the second 875-mL volume of water collected at the tap after a 6-hour stagnation period at field study sites monitored during this project. These results are provided as an indication of typical lead concentrations and percent contribution of the faucet and adjoining premise piping towards first-liter LCR compliance results.

Table 3.16
Lead concentrations in first 125-mL and second 875-mL samples

	Before			After		
Site	Service Line Material	Lead in First 125-mL, µg/L	Lead in Second 875-mL, µg/L	Service Line Material	Lead in First 125-mL, µg/L	Lead in Second 875-mL, µg/L
LSL Replacement Sites						
M-1	Lead	24.7	8.3		-	-
M-2	Lead	4.4	1.9		-	-
M-3	Lead	13.5	12.0		-	-
M-4	lead	12.2	7.3		-	-
D-1	lead	7.1	9.0		-	-
D-2	lead	15.0	11.6		-	-
D-3	lead	5.3	3.5		-	-
D-4	lead	9.6	11.5		-	-
B-1	lead	17.9	5.6	cu	1.9	1.2
B-2	lead	4.0	2.6	cu	4.4	1.5
B-3	lead	3.0	5.4	cu	2.2	5.7
B-4	lead	14..0	7.8	cu	2.5	5.1
T-1	lead	9.2	10.4	cu	5.4	7.8
T-2	lead	6.4	5.5	cu	4.0	1.3
T-3	lead/cu	14.9	14.3	cu	5.0	5.1
T-4	lead	15.8	19.2	lead/cu	11.0	16.7
Faucet Replacement Sites						
F-1	lead/cu	4.1	11.6	lead/cu	12.5	10.1
F-2	lead	19.2	26.7	lead	29.5	32.3
H-1	cu	6.0	1.6	cu	3.0	3.3

If there is a lead service line in place and lead levels measured at the tap are relatively high, the lead derived from all sources (faucet, premise) may be elevated and removal of the service may improve first-liter lead levels. If lead levels are initially low at sites with lead service lines, then removal of the service will not likely improve the total mass of lead or the first-liter lead level, and replacement of the service line may elevate lead levels in the short term. For partial lead service line, there may not be an appreciable improvement in first-liter lead levels by 2 months after the replacement, and there may or may not be an improvement over a longer period of time.

Table 3.17
Percent contribution of first 125-mL and second 875-mL on LCR compliance

	Before			After		
Site	Service Line Material	% Contribution from First 125 mL	% Contribution from Second 875 mL	Service Line Material	% Contribution from First 125 mL	% Contribution from Second 875 mL
LSL Replacement Sites						
M-1	Lead	30%	70%		-	-
M-2	Lead	25%	75%		-	-
M-3	Lead	14%	86%		-	-
M-4	lead	19%	81%		-	-
D-1	lead	10%	90%		-	-
D-2	lead	16%	84%		-	-
D-3	lead	18%	82%		-	-
D-4	lead	11%	89%		-	-
B-1	lead	31%	69%	cu	18%	82%
B-2	lead	17%	83%	cu	30%	70%
B-3	lead	7%	93%	cu	5%	95%
B-4	lead	20%	80%	cu	7%	93%
T-1	lead	11%	89%	cu	9%	91%
T-2	lead	14%	86%	cu	31%	69%
T-3	lead/cu	13%	87%	cu	12%	88%
T-4	lead	11%	89%	lead/cu	9%	91%
Faucet Replacement Sites						
F-1	lead/cu	5%	95%	lead/cu	15%	85%
F-2	lead	9%	91%	lead	12%	88%
H-1	cu	35%	65%	cu	12%	88%

In summary, most of the lead in the first-liter, 6-hour standing sample will likely originate in the premise piping, with a relatively minor amount from the faucet. The lead released from the premise piping could originate from direct lead sources such as 50:50 tin:lead solder or lead in brass components or piping, or from indirect sources such as lead that was incorporated into corrosion by-product scales ("seeding from an upstream lead service line); or lead that was in the water used to flush the system prior to a stagnation period. Removal of the entire lead service line has two definitive benefits, removal of a direct source of lead release into the water from the lead service line and possible removal of a 'seeding' source of lead in downstream piping and appurtenances. Removal of a portion of a lead service line has less definitive benefits. There is often a release of particulate lead immediately after partial removal which can continue for months. In this study, the partial removal of the lead service line did not substantially reduce either the mass of lead measured or the amount in the first-liter sample.

EFFECT OF PIPE-CUTTING TECHNIQUES ON LEAD LEVELS AT THE TAP

The method used to cut an existing lead service line has been implicated as a causative factor in the occurrence of high particulate lead measured at the tap after service replacement. At DCWASA, an evaluation of different pipe cutting techniques was completed (pipe lathe, hacksaw, and pipe cutter), and it was concluded that there was no difference in the lead levels measured at the tap associated with using these different types of equipment (Appendix B).

As part of this study, partial lead service line replacements were completed at Toronto and Boston using two different pipe cutting techniques; a hacksaw and a disc or pipe cutter. Sequential standing 1-liter samples were collected at the kitchen tap before lead service line replacement, the day of the replacement, and for 3 consecutive days after lead service line replacement at each site (see Appendix F for detailed results). Table 3.18 lists the difference in total mass measured at the tap before and 3 days after replacement, and lead levels measured from the first 1-liter sample collected at the tap. The difference in total lead mass is also displayed in Figure 3.8. A negative difference indicates that the total mass of lead measured at the tap during sequential sampling was greater after replacement when compared to before replacement. Disc cutter sites showed better improvement in total lead mass measured at the tap 3 days after replacement when compared to sites where the hacksaw was used. First-liter lead levels did not show any differences, likely because samples were only collected for up to 3 days after replacement. A longer length of time may be needed for first-liter lead levels to be reduced at these replacement sites. However, these results do indicate that the method used to cut the service line during replacement will affect the total mass of lead measured at the tap. Utilizing a coarse cutting method (such as a hacksaw) will cause more disturbance on the surface of the pipe and increase the lead levels measured at the tap after replacement.

Table 3.18
Difference in total mass and first-liter lead levels at pipe cutting evaluation sites

Site	Type of Replacement	Type of Cutting	1st Liter Before Replacement, μg/L	1st Liter 3 Days After Replacement, μg/L	Difference in Total Mass at Tap after 3 days, ug
T5	Partial	Hacksaw	45.8	35.0	54.7
T6	Partial	Hacksaw	11.0	11.0	11.0
T7	Partial	Hacksaw	4.0	5.5	-52.7
T12	Partial	Hacksaw	15.0	10.0	-7.0
T13	partial	Hacksaw	11.0	32.0	-66.0
T8	Partial	Disc cutter	4.9	5.4	-0.4
B5	Full	Pipe cutter	29.4	33.1	79.9
T9	Full	Disc cutter	38.0	48.0	49.0
T10	Partial	Disc cutter	7.0	6.0	174.0
T11	Partial	Disc cutter	17.0	18.0	31.0

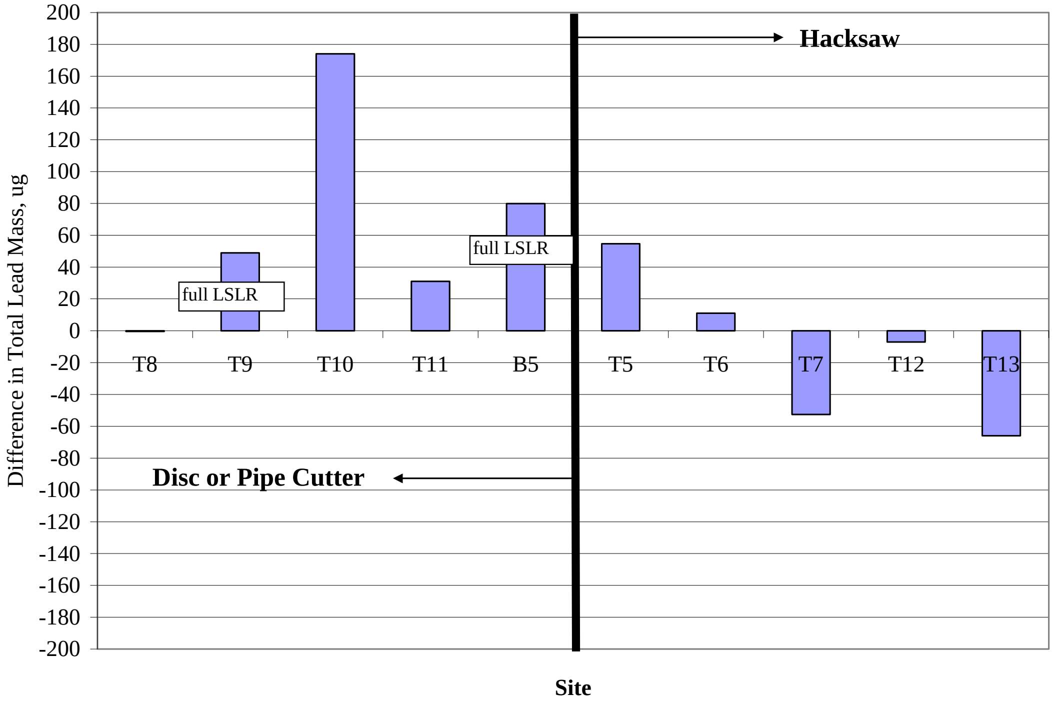

Figure 3.8 Difference in total lead mass measured at the tap at pipe cutting evaluation sites

CHAPTER 4
LEAD LEVEL REDUCTION APPROACHES AND DECISION MAKING CRITERIA

INTRODUCTION

An understanding of the effectiveness of water chemistry changes (treatment) and lead source removal programs in reducing lead levels at the tap provides utilities with the information to make decisions about the best means for both complying with the LCR and reducing overall public exposure to lead in drinking water. The purpose of this chapter is to discuss these lead level reduction approaches, their effectiveness in reducing lead levels at the tap as determined by results from this study, and to present guidelines and decision-making criteria for utilities to assist them in developing approaches for reducing lead at the tap.

LEAD LEVEL REDUCTION APPROACHES

Corrosion Control Treatment

The LCR has been in place now for approximately 16 years, and has resulted in utilities across the United States undertaking a variety of treatment changes to make their finished water quality less corrosive to lead and copper. A relatively smaller number of utilities have also either chosen or been required to physically remove utility-owned lead service line pipes in an effort to lower lead levels measured at the tap. This combination of water chemistry adjustments and removal of lead sources has generally resulted in lower lead and copper levels measured at the tap in standing first-liter samples, and compliance with the LCR’s action levels for these metals. The most recent assessment of national compliance with the LCR’s lead action level indicated that for utilities that serve more than 3,300 people, 96 percent met the action level for lead, and LCR monitoring results for large systems indicated that only 15 of 166 systems were above the lead action level (USEPA 2005b).

In addition, a large body of new information on treatment effectiveness has been developed since promulgation of the LCR in 1991, and this information can be utilized to fine-tune the decision-making process. Examples include the Massachusetts Water Resources Authority (MWRA), where optimization of pH and alkalinity adjustment (pH to 9.5, alkalinity of 40 mg/L as $CaCO_3$) has reduced lead levels by 80 percent in the communities they serve (Smargiassi et al 2006) and the successful use of orthophosphate both in the UK and the US which has significantly reduced lead levels at the tap and enabled compliance with the LCR. Recent audits of UK water companies by the Water Quality Regulator (DWI) have shown that plumbosolvency control measures through pH adjustment and orthophosphate dosing are reducing lead at customers’ taps in many regions of the country with different water compositions. Thames Water in particular, has successfully used orthophosphate for lead control in its system and has seen significant impacts. Implementation of treatment during 2002 and subsequent data collected in 2003 revealed that the level of non-compliance was significantly reduced and by 2004 all areas were within the 95 percent compliance target set by the DWI (Appendix B).

Based on results from this study, corrosion control treatment to reduce the corrosivity of the water towards lead and copper materials is still the best and most cost-effective way to comply with the requirements of the LCR. Corrosion control treatment can also reduce the mass of lead measured at the tap in sequential sample (i.e., lead levels measured at the tap that are not necessarily related to LCR compliance), and therefore reduce public exposure to lead. While most utilities have implemented their optimal or recommended treatment, there are still those who anticipate a source, water quality, and/or treatment change that may necessitate a review of their current treatment approach. There are also utilities that have implemented optimal treatment but still experience lead levels at LCR compliance sites that are at or above the action level, or those that feel their current treatment strategy may not be the most effective for reducing lead levels system-wide (versus reducing lead levels primarily from LCR targeted sites). These utilities should re-evaluate their current treatment approach as a first step in an overall lead reduction strategy.

Lead Source Replacement

Results from this study indicate that replacement of lead based materials can reduce the total mass of lead measured at the tap during sequential sampling, but results are mixed with respect to LCR compliance. Removal of the entire lead service line can reduce the overall mass of lead measured at the tap and improve compliance at individual residential sites, at least in the time frames evaluated for this study. However, results will be utility and site specific. Partial lead service line replacement did not improve LCR compliance, and only minimally reduced the overall mass of lead measured at the tap during sequential sampling. For both partial and full lead service line replacement, elevated lead levels were measured in standing samples in the short term (up to 3 days), and in some cases, levels were quite high. How long these elevated lead levels will persist is likely to be site specific, dependent on the materials and water quality at each site and the amount of disturbance during replacement.

Information on replacement of leaded faucets in this study, although limited, indicated little or no improvement in either first-liter standing lead levels or reductions in total mass of lead measured at the tap during sequential sampling. The potential contribution of meters to first-liter, standing lead levels was estimated to be quite small, unless there was physical disturbance to the meter that caused high, particulate lead levels.

Based on results from this project, lead service lines contributed the greatest percentage of total lead measured at the tap from sequential samples, either from direct contribution of the service and/or the potential for lead from the service to ‘seed’ other parts of the premise piping. The premise piping was the next highest contributor, followed by the faucet. Meters contributed a relatively small amount of lead to the total mass measured at the tap. Therefore, the most effective way to reduce the total mass of lead measured at the tap (as measured during sequential sampling) would be to replace the entire lead service line, followed by replacement of lead sources in the premise piping, the faucet, and then the meter.

With respect to LCR compliance, the major contributors to lead in standing, first-liter samples were the premise piping and the faucet, in that order, since in the majority of cases, the first liter of water collected at the tap represents water that has been exposed to the faucet and premise system only. The presence of a lead service line at an individual site may elevate the contribution of these premise sources by providing an additional source of lead either by ‘seeding’ the premise system with lead or introducing lead derived from the service at the beginning of the stagnation period. Therefore, removal of the entire lead service line may lower the amount of lead that the faucet and premise piping contribute to a LCR compliance sample, and improve LCR compliance over time. This will be dependent on a number of site specific characteristics however, including the age and type of lead based materials in use at particular sites.

Common sense tells us that, in the end, lead source removal is the most certain route to eliminating lead in drinking water. If none of the materials in contact with the drinking water contain lead, then plumbosolvency becomes a moot issue. The authors of the legislation behind the LCR recognized this, but, at the same time, they recognized that wholesale replacement of all leaded materials in plumbing systems was not achievable at that time, both for technical and economic reasons. That legislation was passed 16 years ago, since then, a great deal of progress has been made. The water industry has learned a great deal more about methods of minimizing the leaching of lead from lead surfaces exposed to water, and it has made a great deal of progress in removing lead service lines. This report clearly demonstrates that the consumer’s portion of the lead service line remains the most important unresolved source of lead. This issue is beyond the jurisdiction of local water utilities and other resources will be required if it is to be resolved. Once this issue is resolved, American homes will clearly be on a path toward lead-free drinking water.

GUIDELINES AND DECISION MAKING CRITERIA

Following is a discussion of guidelines and decision criteria for evaluating both treatment optimization and potential programs for the proactive removal of lead sources in the system. These guidelines identify a series of steps that can be taken, with discussion and explanation of key issues that should be considered for each. Again, for LCR compliance, corrosion control treatment optimization should be the first step taken. However, for those utilities that wish to be proactive in their overall response to lead in the system, guidelines and criteria for development of a lead source removal program are also presented. These guidelines and decision-making criteria have been categorized into the following four steps:

- Gather and Evaluate Historical Information
- Collect and Evaluate Additional Data
- Develop Estimates of Reduction in Lead Levels at the Tap
- Select and Implement Programs

With respect to corrosion control treatment optimization, historical data provides utilities with the basis for developing a thorough understanding of their system with respect to current lead levels measured at the tap and distributed water quality conditions. Historical data on water quality and complaints, LCR data, previous corrosion studies completed by the utility, a literature review of alternative treatment approaches, and information from analogous systems with similar water quality, treatment, and materials should be collected.

Gather and Evaluate Historical Information

The first step in evaluating potential lead source replacement programs is to gather any existing information that may be available on typical lead sources in the system, previous replacement programs, the potential for future regulatory and/or standards changes which may impact lead based material in the system, jurisdictional issues unique to each utility, and the availability of replacement materials. In addition to those compliant with NSF/ANSI Standard 61, look for non-leaded components, fittings, and faucets. A literature review of lead-source issues, including the potential for lead leaching from various types of leaded materials in the system and the impact of replacement programs on lead levels and the tap will provide a good basis for future evaluations. Results from this project, including the background information, case study descriptions, and current evaluations of relative contributions of various lead sources provide a good starting point in assembling this information.

Jurisdictional issues will vary by utility, as evidenced by the results of the national survey completed for this project. Replacement of lead source material in premise and distribution systems is complicated by the fact that utilities only have authority to replace the pipes and/or components that are under their jurisdiction. Results from the survey completed for this project indicate that 77 percent of utilities responding claimed ownership of the service line from the main to the curb stop, and would only have the authority to replace the portion of the lead service line piping they owned, i.e., partial lead service line replacement. Premise piping systems are owned and controlled by the property owner. It is important for each utility to have a clear understanding of what they have the authority to replace at the beginning of the process of evaluating potential lead source replacement programs.

Collect and Evaluate Additional Data

Once historical information has been evaluated, it may be determined that additional data may be needed in order to adequately assess the impact that treatment changes or replacing lead sources may have on lead levels measured at the tap. Examples of additional data collection efforts that would be particularly valuable are presented below.

Collect Data on Corrosion Control Treatment Effectiveness

When re-evaluating corrosion control treatment, utilities may opt to conduct additional testing such as bench, pilot or demonstration testing of treatment effectiveness. Data from a pilot study of excavated lead service line piping conducted by the Washington Aqueduct, and provided to this study, is an example of this type of evaluation (Appendix C). The Aqueduct evaluated a variety of phosphate inhibitor and disinfectant approaches on lead release from excavated lead service line piping.

Collect Additional Information on Materials.

Most utilities have already conducted materials surveys in coordination with the LCR and identified Tier 1 sites for LCR monitoring, so in most cases, there will already be sufficient understanding of what the major sources of lead are in the system, and where compliance samples should be collected. What is not typically understood, however, are the specific characteristics of residential sites where compliance sampling will take place. The amount of lead that will be measured at the tap is related to a variety of factors, including water quality, water use, and the specific lead source materials available at each site. The extent of these lead source materials, and their proximity to the tap where water is collected, will affect lead levels measured at the tap.

This project utilized individual site survey information in order to evaluate relative contributions from various lead sources to lead measured at individual sites. Utilities can utilize this same approach and conduct site surveys at selected locations to identify the materials in use (faucet, meter, premise piping and connectors, and service piping). This will entail working with customers to gain entry to the home to identify and measure the internal premise plumbing system. Results from the site survey will need to be evaluated to determine the volume of water in various sections of the residence. Using the materials identified, along with the diameters and lengths of pipe, the volume of water contained in section can be determined (premise piping, lead service line). This information can be used to correlate site information to historical lead level measurements collected at the tap and/or to develop new data collection programs to collect sequential samples at the tap (profile monitoring). The site survey information will provide information on how far back into the premise system the 1-liter LCR-compliance sample will extend, and what sections of the premise system particular samples may represent during profile monitoring.

While it would be unreasonable to expect site surveys to be completed on all compliance monitoring sites (or additional sites), it may be instructive to select a number of representative locations that reflect ‘typical’ characteristics of LCR-monitoring sites and/or other sites of interest and use this information to develop system-wide estimates of site characteristics for LCR-compliance sites. This approach will be more accurate if there is a degree of homogeneity in the sites used for compliance (i.e., approximately the same age, size of residence). This type of ‘special’ investigation may seem onerous and difficult to implement, but for utilities that are struggling with compliance with the LCR, the additional time and effort to thoroughly identify the potential site characteristics that may affect lead leaching at a specific compliance site may be quite useful.

Conduct Additional Tap Monitoring

Monitoring to evaluate the impact that lead sources may have on lead levels measured at the tap can include regulatory monitoring for the LCR and special monitoring to more clearly distinguish relative contributions of various sources (i.e., sequential or ‘profile’ sampling). The LCR requires that the samples be 1 liter in volume. This volume would collect water that has stagnated in the faucet and premise plumbing rather than standing in direct contact with the service line or other lead source further away from the tap. Lead from the service line and/or water meter may also be represented in that 1-liter sample because of the particular site characteristics and flow conditions prior to stagnation, but the regulatory collection protocol makes it difficult to distinguish between these contributing lead sources. This becomes more of an issue the farther away the service line is from the regulatory sampling location within the residence. Special sampling programs, such as collection of sequential samples at the tap or sampling directly from the lead source, may provide more direct evidence of the relative contribution these sources may have on lead at the tap. This project utilized a sequential sampling protocol that involved collection of a series of sequential samples after a minimum 6-hour standing time. Initial samples were smaller volume to isolate the contribution that the faucet may have on first-liter lead levels, followed by 1-liter samples. The number of samples collected was determined by the site survey information completed at each site, in order to collect water that have been stagnant throughout the entire system (tap to main). The results from this type of sequential ‘profile’ monitoring can more clearly show the presence of lead sources, particularly faucets and lead service lines. Different protocols could be developed to evaluate more discrete volumes to pinpoint lead sources more accurately, or to sample at locations that are closer to a particular source (i.e., at the service line entrance to the residence to obtain meter and/or service line lead levels). Appendix F contains a description of the sequential sampling program completed at several utilities or this project, and the case studies contained in Appendix B provide some additional examples of special tap monitoring programs that have been undertaken to evaluate lead levels at the tap.

Conduct Testing of Lead Source Materials

Utilities may also conduct bench-top or pilot testing to evaluate lead leaching from lead based materials in a more direct way to assess water quality impacts on lead leaching from specific lead sources. Pilot studies of both faucets and meters were completed for this project, and a larger pilot evaluation of excavated lead service lines was also described. These testing efforts can provide specific information on the potential for leaching from materials already installed in the system, or evaluate new materials which could be useful in making component choices for a lead source replacement program. Appendix C contains a summary of the protocols and objectives for the pilot evaluations completed for this project.

Evaluate Corrosion Scales

An evaluation of the existing corrosion scales that have developed on lead based materials will provide additional information on how corrosion scales that develop under different water quality conditions may respond to potential water quality changes. The field and pilot studies completed for this project provided excavated lead-based materials for evaluation of the scale, which included identification of the elements and compounds that occurred under different water quality conditions, and solubility characteristics of those compounds that may affect lead release to the water. The results from these evaluations are discussed in Appendices C and F. Documenting the methods of analyses and results obtained from these corrosion scale investigations adds to the body of knowledge for these promising techniques, making them more accessible to utility investigators.

Developing Estimates of Lead Level Reductions at the Tap

The primary alternative for corrosion control for lead and copper is passivation of the surface of the lead-based material by adjusting pH and/or alkalinity or adding an inhibitor. As stated previously, in the 16 years since implementation of the LCR, a large body of new information about treatment effectiveness and implementation issues have been developed. Also, several new documents are available in addition to the original USEPA guidance manuals (USEPA 1992) and AwwaRF publications on lead control (AwwaRF 1990), that can assist utilities in developing estimates of lead level reductions and optimizing corrosion control treatment. These include a second edition of the cooperative research report titled ‘Internal Corrosion of Distribution Systems’ (AwwaRF and DVGW 1996) that provides an overview of current corrosion theory, and a revised guidance manual for selecting lead and copper control strategies (USEPA 2003) which provides a series of easy-to-use flow charts that can be used to identify the most appropriate treatment approaches for control of lead and/or copper for various pH and DIC values. In addition, the USEPA recently published a simultaneous compliance manual that discusses the interrelationships between compliance with the LCR and regulations on disinfectants and disinfectant by-products (USEPA 2007b). These publications provide useful tools for estimating reductions in lead and copper levels for different treatment alternatives, and can be used in association with utility specific data.

Developing estimates of lead reduction from replacement can be difficult unless somewhat quantifiable data exist that ties specific lead sources to lead concentrations. The approach taken in this study was to develop these quantifiable data via collection of sequential samples at the tap and evaluation of pilot testing data on specific lead sources. This type of extensive data gathering program may not be possible for all utilities, therefore use of historical information, background literature and case study descriptions may be used to develop estimates of potential reductions. This project has provided examples of this type of information to the user in one package.

Program Selection and Implementation

Selection and implementation of programs for corrosion control treatment and/or replacement of lead sources will be driven by a number of utility-specific issues. For corrosion control treatment, these factors include future compliance with other federal and state regulations, impacts on existing treatment process effectiveness and operations, and potential secondary impacts such as post precipitation of calcium carbonates, industrial users, aesthetics and customer complaints, public acceptance, and wastewater phosphate and/or zinc discharge and sludge limitations, and costs.

The feasibility of a particular lead source replacement alternative should be evaluated based on a clear understanding of the jurisdiction the utility has over the source (ownership and/or authority), other utility operations and maintenance programs that could impact labor and administrative resources needed for implementation, the availability of local contractors to complete the work, and scheduling of other street maintenance or utility main replacement projects. The feasibility of a particular approach may also depend on the availability of replacement materials, particularly components made from non-leaded brass alloys. Use of components made from these new alloys may require development of new utility specifications. Four case studies contained in Appendix B of this report provide descriptions of no-lead specification processes (East Bay MUD, Los Angeles Department of Water and Power, Louisville Water Company, and Newport News Waterworks) and one (Newport News) has provided an actual example of their specifications for no-lead (Envirobrass) meters. Costs associated with lead source replacement include labor and materials for implementation of the program, follow-up monitoring, and public awareness/education programs. Costs for lead source replacement will vary significantly depending on the extent of the replacement program and local and regional materials and personnel costs. A survey of costs associated with lead service line replacement was completed as part of the survey for this project and is contained in Appendix A. Costs for mitigation of potentially high lead levels that may occur with lead source replacement (particularly partial lead service line replacement) should also be considered, including labor and water costs associated with flushing, and public awareness programs.

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ABBREVIATIONS

AL	Action Level
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
AwwaRF	Awwa Research Foundation
AWWASCo	American Water Works Service Company
BWSC	Boston Water and Sewer Commission
CDA	Copper Development Association
DCWASA	District of Columbia Water and Sewer Authority
DIC	Dissolved Inorganic Carbonate
DWI	Drinking Water Inspectorate
EBMUD	East Bay Municipal Utility District
EPA	Environmental Protection Agency
EQI	Environmental Quality Institute
GCWW	Greater Cincinnati Water Works
km	Kilometer
L	Liter
L/min	Liters per Minute
LADWP	Los Angeles Department of Water and Power
LCCA	Lead Contamination Control Act
LCR	Lead and Copper Rule
LSL	Lead Service Line
LSLR	Lead Service Line Replacement
LWC	Louisville Water Company
m	Meters
MCLG	Maximum Contaminant Level Goal
MDC	Metropolitan District Commission
mg/L	Milligrams per Liter
mL	Milliliter
MWRA	Massachusetts Water Resources Authority
NAS	National Academy of Sciences
NSF	National Sanitation Foundation
OWQP	Optimal Water Quality Parameters
Prop 65	Proposition 65
PWB	Portland Water Bureau
PWD	Philadelphia Water Department
RDT	Random Daytime
SDWA	Safe Drinking Water Act
SFPUC	San Francisco Public Utility Commission
SPS	Seattle Public Schools
SPU	Seattle Public Utility
µg/L	Micrograms per Liter
UK	United Kingdom
UNS	Unified Numbering System

USEPA	United States Environmental Protection Agency
WA	Washington Aqueduct

APPENDIX A

NATIONAL SURVEY OF LEAD SOURCE CHARACTERISTICS AND JURISDICTIONAL ISSUES

NATIONAL SURVEY

A national survey was developed to generate a snapshot of typical industry service line jurisdiction issues and replacement techniques, physical characteristics of service lines, and the presence of lead sources under either utility or customer control. This survey obtained the following key information:

- Legal (ownership) issues related to service line installation, repair, and replacement
- Typical service line lengths
- Typical costs of service line replacements
- Use of leaded materials in the distribution system (meters, leaded joints, fittings, valves)

Results from this survey were compared to information obtain in previous surveys and historical literature in order to develop typical service line characteristics and jurisdictional issues of importance for use in developing the criteria for making cost-effective choices between lead service line replacement and/or corrosion control treatment for reducing lead levels measured at the tap. This appendix summarizes the results of this survey. The actual survey data follows this summary, as well as a copy of the original survey.

APPROACH

The surveys were sent to 90 utilities via email and mail, depending on available contact information. Of these, 70 utilities had participated in past surveys covering Lead and Copper Rule compliance. These surveys included: the AWWA Lead Information Survey (AwwaRF LIS) (AWWA 2005), the Water Industry Technical Action Fund (WITAF) Survey (AWWA 1990), and a survey for AwwaRF Project 2927 "*Installation, Condition Assessment, and Reliability of Service Lines*" (AwwaRF 2007). Since these issues (legal responsibility, use of leaded materials, service line replacement techniques and costs) can vary by region of the country and also by the size of the utility, the survey list was designed to target utilities of different size categories (serving populations in the following categories; <=3300; between 3300 and 50,000; and >50,000) located throughout the United States. Initial response rates were low (14%), so follow-up phone calls were made to 68 utilities. A total of thirty two completed surveys were returned, a response rate of 36%. A Microsoft Excel spreadsheet was developed for recording and analyzing the survey responses.

SUMMARY OF SURVEY RESULTS

The average total length of service lines (main to residence) reported was 55 feet (range of 3 – 83 feet) for older areas, and 68 feet (range of 0 – 110 feet) for newer areas of the distribution system. Average length for the utility portion of the service was 25 feet in older areas (range of 3 – 60 feet) and 27 feet in newer areas (range of 0 – 60 feet). As expected, utilities reported that newer areas had, on average, longer service lines than older, more urban areas of their systems. In comparison, previous evaluations of typical lead service line lengths have estimated somewhat similar distances (Table A.1). The majority of respondents indicated that the water main was located near the curb, followed by off-set from the center of the street.

Seventy seven percent of utilities responding claimed ownership of the service line from the main to the curb stop, and the vast majority also owned the meter (82% of those responding to the question). Average costs of service line replacement (labor and materials) are listed in Table A.2, along with average costs reported from previous surveys conducted by AWWA (AWWA 2005, AWWA 1990) for comparison. Average replacement costs for the utility portion of the service line was less than the average costs of replacing the customer owned portion.

Seven of the utilities that responded to the survey did not have lead service lines or connections in their system. The remainder of utilities reported the number of lead service lines and connections remaining in their systems and the type of LSL replacement program implemented. About half of those responding conducted partial lead service line replacements and the other half conducted full replacements. For most systems, the customers are responsible for all aspects of replacement of their portion of the service lines. The majority of utilities had at least codes or standards for service lines and one-third had developed specifications for the lead content of newly installed components in their system (i.e., no-lead components containing < 0.25% lead).

Table A.1
Average Service Line Lengths

	Average Length of Utility Portion of Service Line, feet (range)		Average Length of Customer Portion of Service Line, feet		Average Total Length of Service Line, feet	
	Urban	Suburban	Urban	Suburban	Urban	Suburban
Current Survey (2006)	25 (3-60)	27 (0-60)	-	-	55	68
AWWA(1990)	13	25	35	48	48	73

Table A.2
Typical Service Line Replacement Costs

	Average Cost of Replacing Utility Portion, $/Service	Average Cost of Replacing Customer Portion of Service Line, $/Service
Current Survey (2006)	$1,261 ($250 - $3000) ($52/lineal foot)	$2,300 ($600 - $4,000) ($46/lineal foot)
AWWA(2005)	$1,756 ($800 - $3200)	$2,144 ($450 - $10,000)
AWWA (1990)	System Size: <10,000 = $48.64/lineal ft >10,000 = $61.85/lineal ft	System Size: <10,000 = $25.95/lineal ft >10,000 = $32.99/lineal ft

AWWA. 2005. *Strategies to Obtain Customer Acceptance of Complete Lead Service Line Replacement.* American Water Works Association. Denver, CO.

AWWA . 1990. *Lead Service Line Replacement: A Benefit-to-Cost Analysis.* Water Industry Technical Action Fund. American Water Works Association. Denver. CO.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

With respect to other lead sources in the surveyed systems, only 10 utilities provided estimates of the number of leaded meters and valves (>8% lead) which may be in their system, and 8 of those reported they had no leaded meters or valves present. Three of thirteen utilities reported they had a program in place to replace lead containing in-line devices with 0.25% lead content meters and/or fittings.

Results from this survey indicate that:

- Estimates of average lengths for utility owned and customer owned service lines are similar to results obtained from previous surveys
- Average service line lengths and costs for replacement varied considerably between utilities
- Utilities generally have authority of the service line from the main to the curbstop, and own the meter, although there are some exceptions
- Property owners are responsible for replacement of their portion of the service line
- Specifications for installation of no-lead components are being implemented at several of the utilities surveyed, and a smaller number have programs to replace lead containing components in their system
- For the utilities responding – there did not seem to be a good understanding of the extent of leaded component use in the system

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AwwaRF 2007. *Installation, Condition Assessment, and Reliability of Service Lines*. Awwa Research Foundation. Denver, CO.

TABULAR SURVEY RESULTS

Tables A.4 through A.6 present tabular summaries of survey results. Table A.4 presents a summary of responses related to population, water supply, and treatment. Table A.5 summarizes service line characteristics, ownership, and legal issues, and Table A.6 presents responses to questions on distribution lead sources. Of the 32 utilities responding, one utility was a wholesale water provider, so was not able to provide information on distribution system issues. In general, 46% of the remaining 31 utilities that responded served a population of >10,000 to 50,000 people, although there was representation from all population categories (<3,300 to >500,000.) The source of supply for most respondents was surface water or a combination of surface and groundwater. Chlorination was the predominant finished water disinfectant used and 65% of respondents were implementing some form of corrosion control treatment. Over 50% of utilities responding indicated that they have made source water and/or treatment changes to their system in the last 5 years, and are planning on making changes in the near future.

Table A.4
Summary of Background Information from Survey

Survey Question	# of Responses	Results	
I-2[1]: Total population served	32	<= 3,300	1
		> 3,3300 and <= 10,000	4
		> 10,000 and <= 50,000	15
		> 50,000 and <= 100,000	2
		> 100,000 and <= 500,000	7
		> 500,000	3
I-3: What type of supply source does your utility rely on?	32	Surface water only	13
		Groundwater only	6
		Combination	13
		Other	2 (in combination with a groundwater or surface water supply)

(continued)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table A.4 Continued
Summary of Background Information from Survey

Survey Question	# of Responses	Results	
I-4: What type of corrosion treatment is practiced?	32	# of system operating at least one plant with corrosion control	21
		# of systems operating at least one plant with pH adjustment	19
		# of systems operating at least one plant with alkalinity adjustment	4
		# of systems operating at least one plant with corrosion inhibitors	11
I-5: What type of finished water disinfection is practiced?	32	Chlorination	24
		Chloramination	4
		Other	2
		None	2
I-6: Has your system made changes to the following in the last 5 years?	32	No	13
		Yes	19
		If yes – what change?	
		Sources of supply	5
		Disinfection	6
		Corrosion control treatment	3
		Other	2
I-7: Does your system plan to make any changes to any of the following during the next 5 years?	32	No	15
		Yes	17
		If yes – what change?	
		Sources of supply	6
		Disinfection	7
		Corrosion control treatment	4
		Other	6

[1] Question I-1 asked for contact information.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table A.5
Summary of Survey Responses on Service Line Characteristics, Ownership, and Legal Issues

Survey Question	# of Responses	Results	
II-1: Total number of service lines	29	Average	51,924
		Maximum	415,011
		Minimum	1,650
		Total	1,557,727
II-2: Location of mains with respect to street right-of-way	31	Centered	2
		Fixed off-set from center	4
		Near the curb:	10
		Other	15
		(Note: 4 indicated all of the above locations 3 indicated two of the above locations)	
II-3: Average total length of service line:	92	Older areas:	
		Main to curbstop	25 feet (average) 3 – 60 feet (range)
		Curbstop to meter	30 feet (average 0 – 83 feet (range)
		Newer areas:	
		Main to curbstop	27 feet (average) 0 – 60 feet (range)
		Curbstop to meter	41 feet (average) 0 – 110 (range)
II-4: Describe ownership of typical service line	95	From main to curbstop owned by:	Utility – 24 Property Owner – 7
		From curbstop to meter owned by:	Utility – 10 Property Owner – 21
		Meter owned by:	Utility – 23 Property Owner – 5

(continued)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table A.5 Continued
Summary of Survey Responses on Service Line Characteristics, Ownership, and Legal Issues

Survey Question	# of Responses	Results	
II-5: Does your utility have (check all that apply)	86	Codes and/or standards for service lines	31
		Authority to set standards for construction, repair, or maintenance of line	30
		Authority to replace, repair, or maintain service line	25
		None of the above	0
II-6: What are typical costs of service line replacement? (labor and materials)	46	Utility-owned replacement	$1261 per service ($250-$3000)
			$52 per linear foot ($6 - $200)
		Customer-owned replacement:	$2300 per service ($600-$4000)
			$46 per linear foot ($4 - $208)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table A.6
Summary of Survey Responses on Distribution System Lead Sources

Survey Question	# of Responses	Responses	
III-1: Does your utility have any lead service lines?	31	Yes	24
		No	7
III-2: What is the current estimated number of lead service lines (both utility and customer-owned) in your distribution system (# and/or %)	51	# Utility lead service lines	21,946 (average) 0 – 280,000 (range)
		% Utility lead service lines	12 % (average) 0 – 38%(range)
		# Customer lead service lines	3,800 (average) 0 – 20000 (range)
		% Customer lead service lines	6% (average) 0 – 13% (range)
		What level of confidence do you have in the estimate of these numbers?	Ranged from Low to High
III-3: Has your system weighed the benefits of managing lead levels at the tap through other means than treatment?	28	Yes	5
		No	23

(continued)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table A.6 Continued
Summary of Survey Responses on Distribution System Lead Sources

Survey Question	# of Responses	Responses	
III-4: If you answered yes to Question III-3 would you be able to discuss this evaluation in a follow-up call?	5	Yes	5
		No	0
III-5: What type of lead service line replacement program does your utility implement?	23	Replace a set number of lines annually	2
		Replace when found during routing maintenance	6
		Replace at customer's request	0
		Replace when needed	6
		Do not have a program to replace lead service lines	2
		Other	7
III-6: Are the lead service line replacements a partial replacement or are they a complete replacement	22	Partial	10
		Full	11
		Both	1
III-7: Are there any criteria that you use to select which lead service lines to replace	9	Yes	3
		No	6

(continued)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table A.6 Continued
Summary of Survey Responses on Distribution System Lead Sources

Survey Question	# of Responses	Responses	
III-8: If you conduct partial lead service line replacement, how much of the total lead service line length remains in service?	11	3/4 of line	2
		2/3 of line	1
		1/2 of line	2
		1/3 of line	1
		1/4 of line	0
		Other	5
III-9: What level of responsibility does the customer have for replacement of their portion of the lead service line?	25	In charge of all aspects of replacement	20
		Pays for replacement conducted by utility	1
		None	3
		Other	1
III-10: Have you conducted any water quality monitoring to evaluate the impact of lead service line replacement on lead levels?	24	Yes	6
		No	18
III-13[2]: Does you utility have any lead service connections (goosenecks)?	31	Yes	21
		No	9
III-14: Estimate service connections that are lead	31		
How many?		Average	25,212
		Maximum	280,000
		Minimum	0
		Total	368,475

(continued)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table A.6 Continued
Summary of Survey Responses on Distribution System Lead Sources

Survey Question	# of Responses	Responses	
What percentage?		Average	16%
		Maximum	67%
		Minimum	0
III-15: Have you replaced lead goosenecks in your system?	33		
How many?		Average: 8,774	8,774
		Maximum: 52,000	52,000
		Minimum: 0	0
		Total: 78970	78,970
What percentage?		Average	35%
		Maximum	99%
		Minimum	0
III-16: Have you conducted any water quality monitoring to evaluate the impact of replacement of lead goosenecks on lead levels?	20	Yes	3
		No	17
III-17: What in-line components in your distribution system may contain lead (i.e. >8% lead content)?	38	Meters	0 (average)
			12% (average reported)
		Valves	52 (average)
			5% (average)
III-18: Do you have a program to replace lead containing in-line devices, i.e. are you installing no more than 0.25 % lead content meters and/or fittings?	13	No	9
		Yes	3

(continued)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table A.6 Continued
Summary of Survey Responses on Distribution System Lead Sources

Survey Question	# of Responses	Responses	
III-19: Have you conducted any water quality monitoring to evaluate the impact of replacement of lead containing in-line devices (meters, valves, fittings, backflow devices, pressure regulators, etc.) on lead levels?	28	Yes No	1 27
III-20: Have you developed specifications for use of low-lead (≤ 8% lead) and/or no-lead (< 0.25% lead) components for your system? (30)	29	Yes No	10 19
III-21: Have you conducted water quality monitoring at the tap to evaluate the contribution of faucets or other premise plumbing materials to lead levels at the tap?	28	Yes No	10 18

---

[2] III-11 Was a repeat question asking how much lead service line replacement costs and III-12 involved a short answer response concerning cutting and excavation techniques.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

ORIGINAL SURVEY

AWWARF 3018
PART 1 SURVEY
SERVICE LINE OWNERSHIP AND LEGAL ISSUES AND LEAD SOURCE INFORMATION

SECTION I: CONTACT INFORMATION AND UTILITY BACKGROUND

Question I-1

Please provide contact information for your utility:

Utility Name: ______________________________________

Contact Name/Title: ____________________________

Address1: ____________________________

Address2: ____________________________

City ____________________________

State ____________________________

Zip: ____________________________

Phone: ____________________________

Fax: ____________________________

Email: ____________________________

Question I-2

What is your total population served?

<=3300
>3300 and <=10,000
>10,000 and <=50,000
>50,000 and <=100,000
>100,000 and <=500,000
>500,000

Questions I-3

What type of supply source does your utility rely on?

_____% Surface Water _____% Ground Water _____% Other (please describe)

____

____

____

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Question I-4
What type of Corrosion Control Treatment is practiced?

Treatment Plant #1:

Name: ______________________________

Is corrosion control practiced at treatment facilities? _____ Y _____ N

If yes, please specify what type:

pH adjustment? _____Y _____N pH treatment goal? __________

Chemicals used:____________________

Alkalinity adjustment? _____Y _____N Alkalinity goal? __________

Chemicals used:____________________

Corrosion inhibitor? _____Y _____N Dosage:____________________

Chemicals used:____________________

Treatment Plant #2:

Name: ______________________________

Is corrosion control practiced at treatment facilities? _____ Y _____ N

If yes, please specify what type:

pH adjustment? _____Y _____N pH treatment goal? __________

Chemicals used:____________________

Alkalinity adjustment? _____Y _____N Alkalinity goal? __________

Chemicals used:____________________

Corrosion inhibitor? _____Y _____N Dosage:____________________

Chemicals used:____________________

Treatment Plant #3:

Name: ______________________________

Is corrosion control practiced at treatment facilities? _____ Y _____ N

If yes, please specify what type:

pH adjustment? _____Y _____N pH treatment goal? __________

Chemicals used:____________________

Alkalinity adjustment? _____Y _____N Alkalinity goal? __________

Chemicals used:____________________

Corrosion inhibitor? _____Y _____N Dosage:____________________

Chemicals used:____________________

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Treatment Plant #4:

Name: ______________________________

Is corrosion control practiced at treatment facilities? _____ Y _____ N

If yes, please specify what type:

pH adjustment? _____Y _____N pH treatment goal? __________

Chemicals used:___________________

Alkalinity adjustment? _____Y _____N Alkalinity goal? __________

Chemicals used:___________________

Corrosion inhibitor? _____Y _____N Dosage:___________________

Chemicals used:___________________

Question I-5

What type of finished water disinfection is practiced?

_____ Chlorination _____ Chloramination

_____ None _____ Other (please describe) ________________________

____

____

Question I-6

Please check if your system has made changes to any of the following in the last 5 years?

Sources of supply -Please describe:____

____

Disinfection -Please describe:____

____

Corrosion control treatment - Please describe:__________________________________

____

Other - Please describe:____

____

Question I-7

Does your system plan to make changes to any of the following during the next 5 years?

Sources of supply -Please describe:____

____

Disinfection -Please describe:____

____

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Corrosion control treatment - Please describe:___________________________________
____

Other - Please describe:____
____

Question I-8
What were your 90% lead levels for the three most recent rounds of monitoring?
Most recent: Year _______________ 90th Percentile lead ______________µg/L
2nd to last: Year ________________ 90th Percentile lead ______________µg/L
3rd to last: Year ________________ 90th Percentile lead ______________µg/L

Question I-9
Would you be willing to share your lead sampling data with the Project Team?
__________ Y ______________N

Question I-10
What are your distribution system optimum water quality parameter goals?
pH: _______________
Alkalinity: _____________mg/L as $CaCO_3$
Other: Parameter: _______________________Goal: ______________

Question I-11
Based on water quality parameter monitoring, what are the maximum, minimum, and averages for these parameters over the last 2 years?

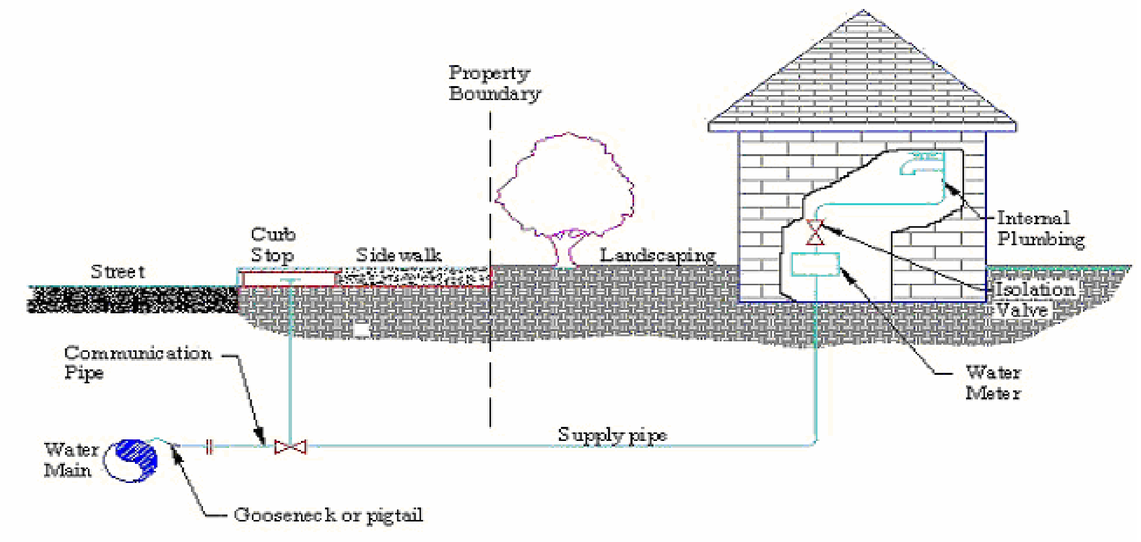
pH: Maximum: _____________Minimum _________________ Average ______________

Alkalinity: Maximum_____________mg/L as $CaCO_3$
Minimum___________ mg/L as $CaCO_3$
Average____________ mg/L as $CaCO_3$

Other: Parameter: _______________________
Maximum: _____________
Minimum _________________
Average ________________

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

SECTION II- SERVICE LINE CHARACTERISTICS, OWNERSHIP AND LEGAL ISSUES



Question II-1

Total number of service lines: ________________________

Question II-2

Location of mains with respect to street right-of-way:

Centered
Fixed offset from center
Near the curb
Other (please describe) ____
____
____

Question II-3

Average total length of service line:
In Older, urban areas:
Main to curbstop ____feet
Curbstop to meter ____feet
In Newer, suburban areas:
Main to curbstop ____feet
Curbstop to meter ____feet

Question II-4

Describe ownership of typical service line:

From Main to curbstop owned by: utility property owner
From Curbstop to meter owned by: utility property owner
Meter owned by: utility property owner
Other (please describe): ____
____
____

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Question II-5
Does your utility have (check all that apply):

Codes and/or standards for service lines?
Authority to set standards for construction, repair, or maintenance of line?
Authority to replace, repair, or maintain service line?
None of the above?

Question II-6
What are typical costs of service line replacement? (labor and materials)

Utility-owned replacement: $/service:____
$/foot:____
Customer-owned replacement: $/service:____________________________________
$/foot:_______________________________________

SECTION III--LEAD SOURCES

Question III-1
Does your utility have any lead service lines?

Yes (go to Question III-2)
No (go to Question III-13)

Question III-2

What is the current estimated number of lead service lines (both utility and customer-owned) in your distribution system?

Utility lead service lines? Number? ______ and/or %____________
Customer lead service lines? Number?_______and/or %____________
What level of confidence do you have in the estimate of these numbers? (e.g. high, medium, low) ____________

Question III-3
Has your system weighed the benefits of managing lead levels at the tap through means other than treatment?

Yes
No

Question III-4
If you answered yes to Question III-3 would you be able to discuss this evaluation in a follow-up call?

Yes
No

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Question III-5
What type of lead service line replacement program does your utility implement?

Replace a set number of lines annually
Replace when found during routine maintenance
Replace at customer’s request
Replace when needed
Do not have a program to replace lead service lines
Other (please describe)____
____
____

Question III-6
Are the lead service line replacements a partial replacement (utility-owned segment of the service line) or are they a complete replacement (utility and customer-owned segments of the lead service line)?

Partial Replacement?
Full Replacement?

Question III-7
Are there any criteria that you use to select which lead service lines to replace (e.g. removal from a given area, lines of a similar age, etc)

yes
no

If yes, what are the criteria?____
____
____
____
____

Question III-8
If partial replacement, how much of the total lead service line length remains in service?

3/4
2/3
1/2
1/3
1/4
Other (please describe) ____
____

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Question III-9
What level of responsibility does the customer have for replacement of their portion of the lead service line?
_____ In charge all aspects of replacement
_____ Pays for replacement conducted by utility
_____ None
_____ Other (please describe): ____
____

Question III-10
Have you conducted any water quality monitoring to evaluate the impact of lead service line replacement on lead levels?
Yes
No

Question III-11
What are the costs associated with lead service line replacement (labor and materials)?*
Utility-owned replacement: $/service:______________________________________
$/foot:____
Customer-owned replacement: $/service:_________________________________
$/foot:__________________________________

Question III-12
What pipe cutting and excavation techniques are used? Please describe:*
____
____
____
____
____
____
____

Question III-13
Does your utility have any lead service connections (goosenecks)?
Yes (go to Question III-14)
No (go to Question III-17)

Question III-14
Estimate how many service connections are lead: ______ connections
What percentage of service connections are lead: ______%

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Question III-15
Have you replaced lead goosenecks in your system?
How many? ______
What percentage? ______%

Question III-16
Have you conducted any water quality monitoring to evaluate the impact of replacement of lead goosenecks on lead levels?
Yes
No

Question III-17
What in-line components in your distribution system may contain lead (i.e. > 8% lead content)?
_____ Meters: estimate how many meters may contain lead: ______# or _____%
_____ Valves: estimate how many valves may contain lead: ______# or _____%

Question III-18
Do you have a program to replace lead containing in-line devices, i.e. are you installing no-lead (no more than 0.25 percent lead) meters and/or fittings in new residences or as part of your periodic replacement program?*
No
Yes (please describe) ____
____
____
____
____

Question III-19
Have you conducted any water quality monitoring to evaluate the impact of replacement of lead containing in-line devices (meters, valves, fittings, backflow devices, pressure regulators, etc.) on lead levels?
Yes
No

Question III-20
Have you developed specifications for use of low-lead ($\leq$ 8% lead content) and/or no-lead (< .25% lead content) components for you system?
Yes
No

Question III-21
If you answered yes to III-20, can you provide a copy of these specifications when returning the survey?
Yes
No

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Question III-22
Have you conducted water quality monitoring at the tap to evaluate the contribution of faucets or other premise plumbing materials to lead levels at the tap?

No
Yes (please describe)____
____

Question III-23
Do you have any additional information on potential lead sources in your system and any lead source replacement efforts you have undertaken that you'd like to share? Please describe (or send a copy of the report to HDR, c/o Amie Hanson):

____
____
____
____
____
____
____
____
____
____
____

SECTION IV- CASE AND FIELD STUDY PARTICIPATION

Question IV-1
Would your utility be interested in providing information and historical data on your experiences with

Partial and/or Full Lead Service Line Replacement,
Replacement of Utility-owned in-line devices containing lead
Replacement of privately owned premise piping and end-point devices containing lead
Other (please describe)____
____
____
____
____
____

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Question IV-2

Would your utility be interested in collecting field data on the contribution of lead sources on lead levels at the tap?

Yes
No

If yes, please provide contact information (if different that Question I-1)

Contact Name/Title: ________________________________
Address1: ________________________________
Address2: ________________________________
City, State, Zip ________________________________
Phone: ________________________________
Fax: ________________________________
Email: ________________________________

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

APPENDIX B

CASE STUDIES OF LEAD SOURCE REPLACEMENT AND TREATMENT

INTRODUCTION

Several utilities provided historical information to document their experiences with partial and full lead service line replacement, leaded meter replacements, implementation of low-lead fixture replacement programs, and use of phosphates to control lead. Utilities that provided information for case studies of their experiences included:

- Greater Cincinnati Water Works, Cincinnati, OH
- District of Columbia Water and Sewer Authority (DCWASA), Washington D.C.
- East Bay Municipal Utility District (EBMUD), Oakland, CA
- Los Angeles Department of Water and Power (LADWP), Los Angeles, CA
- Louisville Water Department, Louisville, KY
- Madison Water Department, Madison, WI
- Newport News, VA
- Philadelphia Water Department (PWD), Philadelphia, PA
- Portland Water Bureau (PWB), Portland, OR
- San Francisco Public Utility Commission (SFPUC), San Francisco, CA
- Seattle Public Schools, Seattle, WA
- Thames Water, London, UK

This appendix contains these case studies. Each is formatted to include an upfront summary of water quality, treatment, and lead source issues, followed by a written discussion of utility experiences.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Greater Cincinnati Water Works
Cincinnati, Ohio
AwwaRF Project 3018 Case Study

Utility Profile

Source water	Ohio River – 90% Great Miami Aquifer– 10%
Surface treatment	Treatment at the surface water treatment plant includes coagulation, sedimentation, pH adjustment, rapid sand filtration, granular activated carbon contacting, a second pH adjustment, chlorine disinfection, sodium hexametaphosphate for sequestration, and fluoride addition.
Groundwater treatment	The groundwater treatment process consists of lime softening, chlorination, sodium hexametaphosphate for sequestration, fluoride addition, and granular media filtration.
Corrosion control treatment	Sodium hydroxide and lime are added at the surface water treatment plant to adjust pH to 8.6. Lime is added at the groundwater plant to adjust pH to 9.0.
Daily demand	Average daily demand: 133 MGD
Total customer population base	~1.1 million
Service line ownership	Utility-owned from main to curbstop. Customer-owned from curbstop to meter.
Lead service lines	Total Number: 234,000
Type of replacement program	Partial lead service line replacement program

LCR BACKGROUND

The Greater Cincinnati Water Works (GCWW) provides drinking water to ~1.1 million people in the greater Cincinnati metropolitan area, of which approximately 500,000 are retail customers. The sources of water are the Ohio River and the Greater Miami Aquifer. Corrosion control treatment utilizes pH adjustment at both their surface water and groundwater treatment plants to control lead. Most recent LCR monitoring data (2006) indicated that the 90th percentile for lead was 8.1 •g/L. Since 1980, GCWW has conducted numerous studies on lead levels at customers' taps. These studies have included evaluation of partial vs. full replacement of service lines, the impact of flushing on tap lead levels, and leaching of lead from system components, such as meters and fittings. Results of these studies are summarized below.

LEAD SERVICE LINE REPLACEMENT EVALUATION

GCWW compared the impacts of partial versus full replacement of lead service lines in a study conducted in 1991 and a follow-up study in 1999. In the earlier study, GCWW sampled customers' homes for lead levels before, directly after, and nine months after partial service line replacement. They found that lead levels could be as high as 0.3 mg/L immediately after partial replacement, but were significantly lower nine months later.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

In the second study, GCWW investigated the impacts of partial vs. full service line replacement at 21 sites (Swertfeger et al 2006). The sites were divided into four groups. Partial service line replacement using normal procedures were completed at five sites (Partial Changeover); six additional sites had partial replacements, however Teflon sleeves were used to cover the cut end of the service so it would not be exposed to water (Partial with Sleeve); and five sites had full replacements (Complete Changeover). GCWW also conducted monitoring at five sites that did not have replacements to serve as a control.

At all sites, 750 mL samples were drawn after a minimum 6 hour stagnation time, and after a 3-minute flush and a 10-minute flush. Samples were collected one week before replacement, one week after replacement, and each month for one year after service line replacement. During the course of the study, the finished water pH was increased from approximately 8.5 to 8.8. Samples collected at all sites, with the exception of the initial samples, and the 1 month sample for Complete Changeover sites, were collected when the finished water pH was approximately 8.8.

Figure B.1.1 presents results of GCWW's second study. The red dashed line in the figure represents when the service line was replaced and the grey dashed line represents when the finished water pH was adjusted from 8.5 to 8.8.

This study determined that partial replacements resulted in a spike in lead levels after partial replacement. This increase in lead levels lasted less than one month after replacement. GCWW's results indicate that partial replacement did not result in benefits over leaving the service line in place over the long-term period. Full replacement did reduce lead levels overall (Swertfeger 2005, Swertfeger et al 2006)

ADDITIONAL STUDIES

In addition to studying service line replacement, GCWW has investigated other distribution system components and the potential for these components to contribute to lead levels at customers' taps. In one study, GCWW conducted monitoring at one home over a 2-year period, beginning in 1990. First draw (minimum 6-hour stagnation) were collected, as were samples after a variety of flushing times. GCWW found that lead levels decreased with flushing, however, lead was never completely eliminated from the tap water. By evaluating flushing volumes, GCWW determined that the lead source was the service line or household plumbing, not distribution main.

GCWW evaluated lead leaching from meters by filling them with water and collecting a sample after a six hour stagnation period. The meters evaluated included an older, brass meter from the distribution system and a newer, no-lead Envirobrass® meter. The sample collected from the older, brass meter exhibited a lead level of 1.240 mg/L while the sample from the newer, Envirobrass® meter had a lead level of 0.028 mg/L.

Lead release from newer, non-leaded brass fittings (0.2% lead content) and fittings manufactured from an alloy with 8% lead content were also studied. The non-leaded fittings (a coupling, ferrule, and curb stop) released much lower lead levels than the 8% lead content fittings after the water was allowed to stand in the fitting for 6 to 18 hours.

REFERENCES

Swertfeger, J. 2005. Personal Communication.

Swertfeger, J., D.J. Hartman, C. Shrive, D. Metz, J. DeMarco. 2006. *Water Quality Effects of Partial Lead Replacement*. Presented at the AWWA Annual Conference, San Antonio, TX. June 2006. American Water Works Association. Denver, CO.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

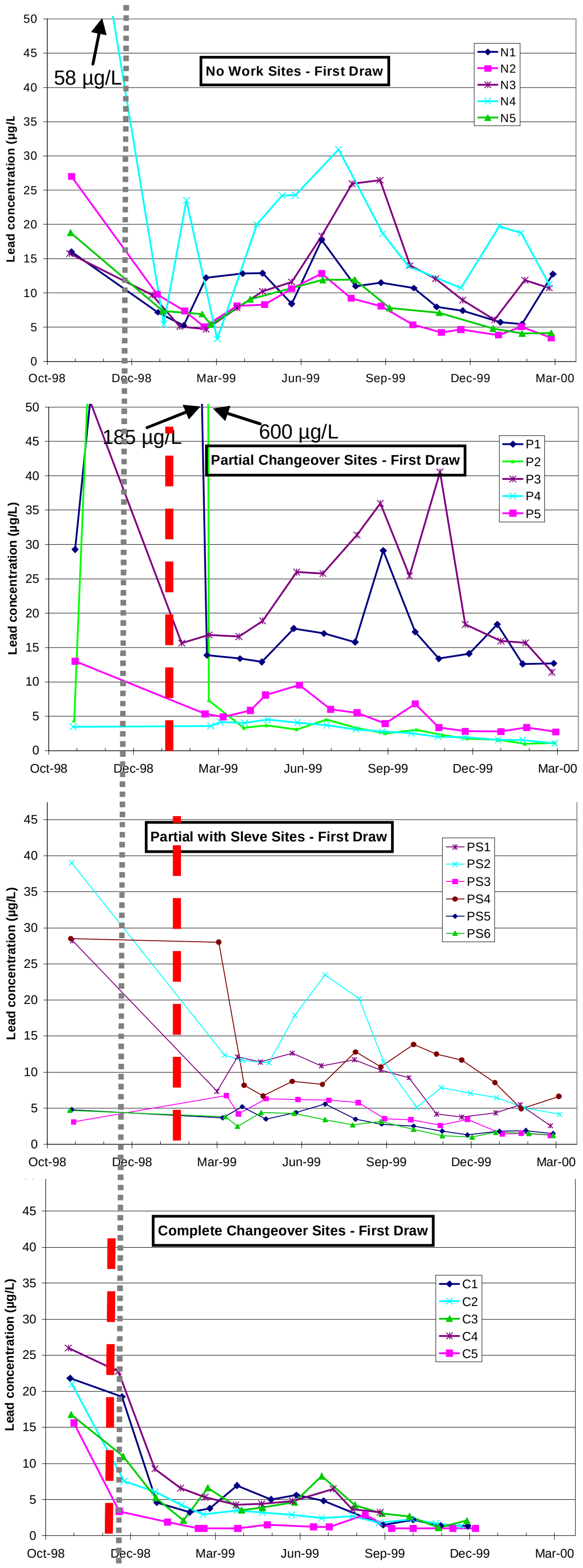


Figure B.1.1 First draw lead concentrations from all study sites.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Utility Profile

Source water	Potomac River
Surface treatment	2 Washington Aqueduct treatment plants using alum coagulation, filtration, lime addition for pH adjustment, final disinfection with chloramines.
Groundwater treatment	None
Corrosion control treatment	Orthophosphate addition.
Daily demand	Average daily demand: 123.6 MGD
Total customer population base	500,000
Service line ownership	Customer-owned from water meter and shut-off valve at property line.
Lead Service Lines	Number: 120,000
Type of replacement program	Lead service line replacement

LCR BACKGROUND

DCWASA relies entirely on surface water purchased from the US Army Corps of Engineers Washington Aqueduct (WA) and therefore, LCR compliance is a joint effort between the WA and DCWASA. Since 1992, when the LCR came into effect, DCWASA has conducted 18 rounds of customer tap sampling for compliance with the LCR. Results of the tap sampling efforts are presented in Table B.2.1.

WA and DCWASA were designated as being optimized for corrosion control by EPA Region III in 1997, on the condition that finished water maintains a positive Langelier Saturation Index through pH adjustment and WA/DCWASA study the feasibility of alternative corrosion control treatments. In 2000, the conditions for optimized corrosion control were adjusted, to require that WA and DCWASA meet a minimum pH of 7.0 throughout DCWASA's distribution system. Treated water pH was to meet a range of minimum pHs from 7.4 – 7.8, varying based on the calendar month. The designation of optimal corrosion control was again changed in 2004. This designation was based on the use of orthophosphate in one pressure zone of DCWASA's system and was later changed to apply to DCWASA's entire distribution system. The finished water target pH was set at 7.7, with a minimum pH in DCWASA's distribution system of 7.2.

Table B.2.1
DCWASA Lead Tap Sampling Results (1)

Monitoring Period	Lead 90th Percentile (mg/L) (Action level = 0.015)
Jan – Jun, 1992	0.018
Jul – Dec, 1992	0.015
Jan – Jun, 1993	0.011
Jul – Dec, 1993	0.037
Jan – Jun, 1994	0.022
Jul – Dec, 1994	0.012
Jan – Jun, 1997	0.006
Jul – Dec, 1997	0.008
Jul – Dec, 1998	0.007
Jan – Jun, 1999	0.005
Jul – Sept. 1999	0.012
July 2000 – June 2001	0.036
July 2001 – June 2002	0.075
January – June 2003	0.040
July – December 2003	0.063
January – June 2004	0.059
July – December 2004	0.059

(1) As reported by DCWASA

LEAD SERVICE LINE REPLACEMENT PROGRAM

Because of tap samples that exceeded the lead action levels, DCWASA has been required to replace 7% of their lead service lines each year since 2004. As part of meeting this requirement, DCWASA enhanced its LSLR program by increasing the percentage replaced annually to approximately 10%. DCWASA submits an annual report to the EPA detailing replacement activities for the past year and summarizing plans for the next year of replacements.

DCWASA prioritized lead service line replacement based on:

- Results of tap samples for lead taken at sites served by a lead service line, and
- Whether streets were available for non-emergency excavation.

In order to prioritize replacement based on tap sample results, DCWASA identified the lead service lines in the system with the highest concentrations of lead, and compared those locations with streets that were not under moratorium by the District of Columbia Department of Transportation (DDOT)(moratorium streets are recently reconstructed roads that with special permitting requirements). Blocks that were not under DDOT moratorium, and had the most lead services and highest lead levels were given priority status. In addition, locations that were found to have very high lead concentrations with residents that are susceptible to lead, i.e. pregnant women, children under the age of 7, etc., as selected by the District of Columbia Department of Health, were prioritized for replacement.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

USE OF LEAD PROFILES TO INVESTIGATE LEAD SOURCES

DCWASA has used lead profiles to investigate distribution lead sources. Lead profiles are consecutive samples collected to represent water quality conditions in different areas, including in-house plumbing and the service line. Giani et al. (2004) discussed DCWASA's efforts in developing this monitoring, which included:

- Investigating primary sources of lead at customers' taps;
- Looking for contaminants which are co-occurring with lead; and
- Determining if lead at the tap is occurring in particulate or dissolved form.

In this study, profiles were developed to capture details on lead levels from the sink to the end of the service line connected with DCWASA's main. This sampling was conducted in five homes with lead service lines that had experienced lead levels above the lead action level during the last two years of sampling. Additionally, a profile was developed to compare the impacts of partial lead service line replacement in one home. In comparing the lead profiles, the following conclusions were made (Giani et al. 2004):

- While actual lead levels, including maximum values, varied for the five homes, each profile was bell-shaped, indicating that the majority of lead originated from the service line.
- The majority of the lead was in the dissolved form.
- In four of the five homes sampled, lead levels did not decrease to below the lead action level, even after the water had run for several minutes as part of collecting the lead profile sampling.
- In comparing the lead profiles before and after partial replacement of the lead service line, lead levels after partial replacement were approximately one-half the lead levels prior to partial replacement. However, both profiles shared a bell-shaped curve indicating that the majority of lead originated from the service line.

PARTIAL LEAD SERVICE REPLACEMENT IMPACTS.

DCWASA has also studied the impacts of partial lead service line replacement on lead levels at customers' taps as reported by Wujek (2004). A review of DCWASA data collected on partial lead service line replacements indicated some locations with very high lead levels directly after the partial replacement was performed. DCWASA wanted to determine if this was related to flushing practices or could be minimized by the replacement procedure. Wujek (2004) described the results of sampling at seven residences conducted prior to partial replacement and for a duration of two weeks after replacement was conducted. DCWASA used different pipe cutting equipment during these replacements: pipe lathe, hacksaw, and pipe cutter. Eleven samples were collected at each tap in a chronological order to represent lead levels in different locations (internal plumbing, lead service line, and main). The sampling protocol for these samples was developed by DCWASA in coordination with the EPA. Samples were collected from the kitchen sink after at least six hours of standing and the aerator was removed from the kitchen faucet. Samples were collected at predetermined intervals to capture the following:

1. 1st liter of water,
2. 2nd liter of water,
3. 4th liter of water,
4. 6th liter of water,
5. 8th liter of water,
6. 11th liter of water,
7. 14th liter of water,
8. 18th liter of water,
9. 22nd liter of water,
10. 3 minute flush, and
11. 10 minute flush.

Samples collected before the partial replacement was performed indicated that, on average, samples representing internal plumbing and lead water services contained lead levels that were higher than the LCR action levels. After partial replacement, only the samples representing the partial lead service had lead levels higher than the action level.

Overall, the average lead levels from all sites were significantly higher before the replacement than after. The highest average lead level measured from sequential samples collected before replacement was approximately 60 ppb and, the highest average lead level measured from sequential samples collected after replacement was approximately 17 ppb. There was no significant change in lead levels during the subsequent two weeks. The study determined that flushing immediately after replacement of a lead service line reduced tap lead levels caused by construction and that the disturbance of the existing line when performing a partial replacement did not significantly increase lead levels in delivered water. The study also reported that there was no significant difference in the lead levels associated with using different construction equipment (Wujek 2004). After completion of this study, DCWASA implemented flushing requirements for lead service line replacement (Wujek, 2004) as follows:

- The service must be flushed at an external hose bib for at least 15 minutes; or
- The customer must conduct appropriate flushing inside for 15 minutes.

CONTRIBUTION OF METERS TO LEAD LEVELS AT CUSTOMERS' TAPS

In an effort to identify sources of lead in the distribution system, DCWASA also conducted a laboratory investigation to determine if meters could be contributing a significant amount of lead to water at customers' taps (Keefer and Giani 2004). The LCR requires meters to have no more than 8% lead. Over two-and-one-half months, DCWASA tested two new bronze water meters, using waters treated in three ways: 1) drinking water with free chlorine as a disinfectant; 2) drinking water with chloramines as the disinfectant; and 3) chloraminated drinking water containing phosphate as a corrosion inhibitor (Keefer and Giani 2004). Table B.2.2 presents the average quality of water flushed through the meters during the three different treatment schemes.

In the laboratory, each meter was flushed for one hour with the water, then water was allowed to stagnate in the meter for various periods of time ranging from 15 minutes to 23 hours. After the stagnation period, a 700 ml sample (volume contained in each meter) was drawn from each meter and sampled for lead levels.

Each of the waters caused lead leaching from the meters, with the chlorinated and chloraminated waters causing levels as high as 160 ppb, and 140 ppb, respectively. The water containing a corrosion inhibitor exhibited significantly less leaching, with a maximum lead level of about 22 ppb. All three exhibited a logarithmic correlation between the level of lead leaching and stagnation time. Laboratory results also indicated that corrosion control had an immediate impact on lead leaching. Lead levels increased by 100% within 24 hours of switching from the chloraminated water containing phosphate to the chloraminated water with no corrosion control (Keefer and Giani 2004). Finally, DCWASA conducted lead profile monitoring at a home using a bronze meter and a copper service line. The profile indicated that the lead at the tap appeared to originate primarily from the customers' in-house plumbing (Keefer and Giani 2004). The disparity between laboratory and field settings may be due to dilution effects and/or the age of the meter.

Table B.2.2
Average Water Qualities during Experiment

Parameter	Chlorinated Water	Chloraminated Water	Chloraminated Water + Phosphate
Free chlorine (mg/L)	3.31	0.40	0.40
Total Chlorine (mg/L)	3.65	3.10	3.10
pH	8.13	7.80	7.54
Alkalinity (mg/L as $CaCO_3$)	68	70	70
Calcium Hardness (mg/Las $CaCO_3$)	94	97	97
Orthophosphate (mg/L)			3.1

Source: Adapted from Keefer and Giani 2004.

SUMMARY

DCWASA is conducting replacement of at least seven percent of lead service lines each year as required by the EPA, giving highest priority to those lines with highest lead levels. In coordination with the EPA, they have developed a protocol for developing lead profiles which has given them an opportunity to study the possible origins of lead levels at the tap. In addition to this activity, DCWASA has conducted a study to determine the best method for performing a partial lead service line replacement. They found no difference in lead levels measured at the tap when different construction equipment was used, and lead levels were reduced due to flushing immediately after replacement. Finally, DCWASA has conducted a study of the contribution of bronze meters to tap lead levels and concluded that lead can leach from meters in a laboratory setting, but field sampling indicated that in-house plumbing was the major contributor to lead measured at the tap.

REFERENCES

Giani, R., M. Edwards, C. Chung, and J. Wujek. 2004. Use of Lead profiles to Determine Source of Action Level Exceedences from Residential Homes in Washington, DC. DCWASA

Keefer, W., and R. Giani. 2004. Lead Investigation: Bronze Water Meters.

Wujek, J. 2004. Minimizing Peak Lead Concentrations after Partial Lead Service Replacements. DCWASA.

East Bay Municipal Utility District
Oakland, CA
AwwaRF Project 3018 Case Study

Utility Profile

Source water	Mokelumne River watershed (90%) Local East Bay watershed (10%)
Surface treatment	Three in-line plants (Mokelumne River supply) with coagulation, filtration, chlorine disinfection, chloramine residual addition. Two conventional plants (local reservoir supply) with coagulation, flocculation, sedimentation, ozonation, filtration, chlorine disinfection, chloramine residual addition. One standby plant (local reservoir supply) with coagulation, flocculation, sedimentation, filtration, chlorine disinfection, chloramine residual addition.
Groundwater Treatment	None
Corrosion control treatment	pH adjustment with calcium hydroxide and sodium hydroxide.
Daily demand	Average daily demand: 210 MGD
Total customer population base	1,300,000
Service line ownership	Customer owned from meter
Lead service lines	None
Type of replacement program	Meter replacement specifications: Old meter and service line fittings replaced with non-leaded parts by attrition

LCR BACKGROUND

The East Bay Municipal Utility District (EBMUD) has long recognized the necessity of corrosion control to provide customers with high quality water. EBMUD practiced corrosion control through pH adjustment well in advance of the Lead and Copper Rule requirements. As a result, initial compliance monitoring in 1992 indicated that the system was already optimized for corrosion control. Table B.3.1 summarizes the historical compliance monitoring data. As the data show EBMUD's 90th percentile results have consistently been below the LCR action limit.

Table B.3.1
EBMUD Historic LCR Monitoring Results

	Monitoring Period				
	September 2002	September 1999	September 1998	November 1992	June 1992
LEAD*					
ACTION LEVEL = 0.015					
Average	0.003	0.003	0.002	0.004	0.005
90th percentile	0.007	0.004	0.004	0.006	0.010
Maximum	0.010	0.051	0.012	0.016	0.032
COPPER *					
Action level = 1.3					
Average	0.037	0.046	0.036	0.024	0.056
90th percentile	0.064	0.074	0.065	0.057	0.214
Maximum	0.139	0.210	0.095	0.190	0.360

*All results are expressed in mg/L

HOUSEHOLD LEAD REDUCTION ACTIVITIES

EBMUD first implemented replacement activities to reduce household lead concentrations in 1985 with the commencement of a lead service line replacement program. Between 1985 and 1992, EBMUD proactively replaced known lead service lines. The program addressed only the utility owned portion of the service line. The total number of lead service lines replaced by the program was one-thousand. Because of the relatively small number of service lines that required replacement the program did not include any type of customer incentive for simultaneous replacement of the customer side service line. This program was completed prior to beginning LCR compliance monitoring requirements. Between 1992 and 2002 EBMUD conducted compliance monitoring and continued pH adjustment for corrosion control.

In 2002, EBMUD implemented a program to further reduce the potential sources of household lead through the replacement of brass constructed meters and service line fittings. The objective of the program was to further address sources of lead in customer service connections. This is an attrition program that focuses on removing the oldest equipment from the system first. Under the program EBMUD replaces obsolete meters and fittings with California Proposition 65 compliant “no-lead” meters and fittings.

EBMUD implemented its meter replacement program through incorporation of material specifications associated with multi-year contracts for the annual replacement of meters and fittings. Fiscal year 2002 was the first year these “no lead” specifications were in effect. Through the specifications approach EBMUD included a “no lead” provision that requires the installation of meters and fittings whose components, individually, do not exceed a lead content not of 0.25%.

In order to develop the specification EBMUD conducted side-by-side performance and lead leaching tests of brass and “no lead” meters. The testing compared ten of EBMUD’s existing stock of brass water meters and ten Proposition 65 identified “no lead” meters. The testing revealed that the “no lead” meters reduced leached lead levels by at least 72% and as much as 98% over the previously specified brass component meters. Based on the results EBMUD revised equipment specifications to require California Proposition 65 defined “no lead” meters and service line fittings for all replaced and new installations.

In 2005 the “no lead” meter and fitting program was in its third year of implementation. Under the program EBMUD contracts for the replacement and installation of approximately 15,000 small water meters, 150 large water meters, and 15,000 curb stops annually.

Based on fiscal year 2005 figures, meter replacement/installation costs were $845,000. EBMUD estimates that the specification of “no lead” materials resulted in a 7% increase ($59,150) in program cost.

EBMUD’s qualitative objective of removing potential sources of lead from the customer service connections is being addressed and achieved through the program. Since EBMUD was previously optimized for corrosion control there were no established quantitative objectives associated with the program. As such EBMUD does not conduct pre- and post-replacement sequential lead monitoring at replacement sites. Based on the side-by-side meter testing the assumption is that lead levels, already below the LCR action are being further reduced.

SUMMARY

The EBMUD “no lead” meter and fitting replacement program is currently scheduled for continuance with the ultimate goal of removing all sources of lead up to premise piping. The increased costs of the program are considered acceptable, especially in light of potential legal and potential financial ramifications that Proposition 65 poses for the utility. To date EBMUD considers the program to be a success at protecting public health with inconsequential additional financial burden.

Los Angeles Department of Water and Power
Los Angeles, CA
AwwaRF Project 3018 Case Study

Utility Profile

Source water	Los Angeles Aqueduct, State Aqueduct, Colorado River Aqueduct, local groundwater
Surface Treatment	Screening, ozonation, direct filtration, chlorination, and fluoridation
Groundwater Treatment	Chlorination
Daily demand	550 MGD
Total customer population base	3.9 million
Lead Service Lines	None
Type of replacement program	Water meter replacement; removal of lead goosenecks.

LCR BACKGROUND

The Los Angeles Department of Water and Power (LADWP) does not have lead in its raw water sources or its distribution system. LCR monitoring results conducted between 1992 and 2004 indicate that 90th percentile lead levels at residential taps are less than the lead action level of 15 •g/L.

METER REPLACEMENT PROGRAM

LADWP initiated a No-Lead Brass Program as a result of a legal settlement regarding substandard valves and other parts supplied to the utility that contained up to 40 percent more lead than allowed by contract specifications. In 1998 LADWP tested 195 parts supplied under contract and found that 68 percent failed to meet contract specifications. The measured lead levels in drinking water did not result in water quality problems to LADWP's customers or violate any EPA action levels for lead. Settlement funds were used to initiate the program in 2001. LADWP's proactive program to change out its leaded brass parts is consistent with USEPA's goal of minimizing lead exposures to the public and the utility's practice of improving on regulatory standards whenever practical and technically feasible.

LADWP uses two different alloys in the No-Lead Brass Program. The alloy used for waterworks fittings (curb valves, meter tailpieces, etc.) is Federalloy I (version 836) with a 0.1% maximum lead content. LADWP testing of production pieces revealed a range of lead concentrations from 0.07% to 0.09%. The alloy used in meters is Sebiloy II (a.k.a. Envirobrass®), with a 0.25% maximum lead content. LADWP testing of production pieces revealed a range of lead concentrations from 0.12% to 0.18%. These testing results indicate that both Federalloy and Sebiloy could probably meet a 0.2% lead limit. LADWP was notified recently that Federal Metals may change the Federalloy composition, which would invalidate past conclusions.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

The LADWP system has one type of customer service, the Western or warm-climate service as illustrated in Figure B.4.1.

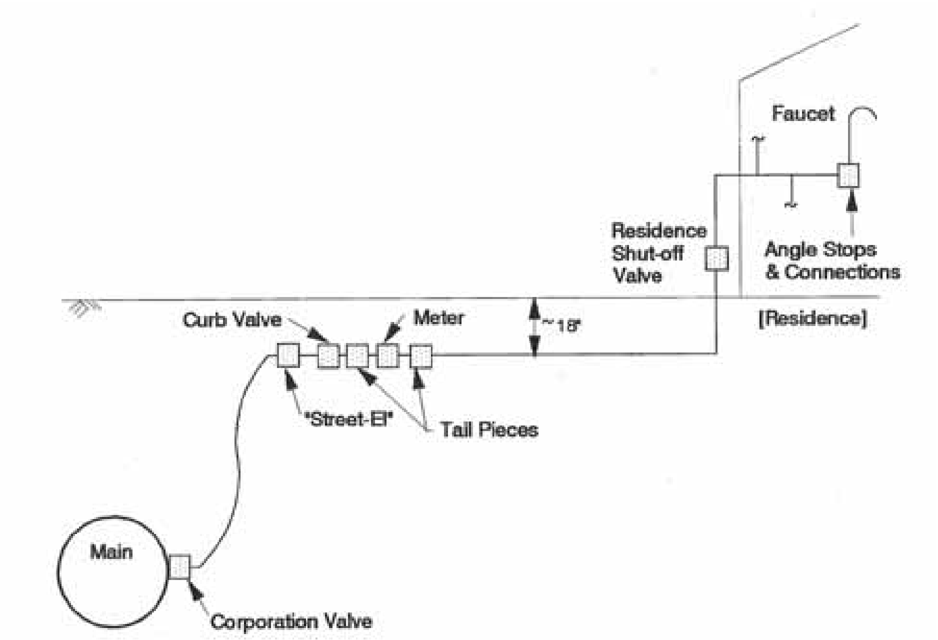


Figure B.4.1. Diagram of Typical Warm Climate Residential Service (Provided by Heumann 2005)

LADWP began installing only non-lead meters in 2001 and intends to replace all meters (~700,000) by 2016, with an annual replacement goal of 40,000 meters. As of July 5, 2006, there were 723,250 service connections (88 percent of which are residential) and more than 171,000 meters have been replaced with non-leaded meters. Meter replacement normally includes replacement of meter couplings (a.k.a. tail pieces, see Figure B.4.1), so approximately the same number of tail piece pairs has also been replaced. In addition, when a meter is replaced, the curb valve is sometimes replaced. Since 2001, more than 70,000 curb valves have been replaced. This program will continue for the foreseeable future.

In the 4 years since LADWP began installing the no-lead brass meters, the utility has not seen fracture failures or leaks at a frequency different from older brass meters, however, failures are not expected in the early years of the program. Meters retrieved and tested after 4.5 years of service had no structural weakening. LADWP is currently testing meters for changes in leaching characteristics and to date has found no significant changes.

In 2001, LADWP compared meter replacement costs for both leaded and non-lead brass including the meter, curb valve and tailpieces as summarized in Table B.4.1. The non-lead brass meter replacement costs were 30 percent higher than the leaded brass alternative, with installation done by the utility (Heumann 2005).

Table B.4.1
Cost Comparison for High and No Lead Bronze Meters Installation at a Typical Service at LADWP (materials only)

Brass component (1 inch)	High lead bronze (85-5-5-5 bronze)	No lead bronze	Cost difference
Curb valve	$17.46	$19.17*	$1.71
Tail piece 1	$3.86	$6.64*	$2.78
Tail piece 2	$3.86	$6.64*	$2.78
Water meter	$18.04	$23.80+	$5.76
Totals	$43.22	$56.25	$13.03 (30%)

* Federalloy + SeBiloy

Table B.4.2 presents the average full costs (i.e. with overheads) for new 1-inch service line installations at LADWP, based upon over 800 installations from July 1, 2005 to March 31, 2006. Labor hours and tool expenses are the same for non-lead and leaded brass installations done in the past. Materials are broken down into categories for "non-lead materials" and "other materials". LADWP is only allowed to charge customers for costs incurred, and the total service line cost corresponds to the current charge for a new 1-inch service line. The service line cost is also calculated for leaded brass, using a non-lead materials cost differential of 30 percent (as determined by LADWP on comparative bids in 2001). The service line cost increase attributable to the change to non-lead brass is 2 percent.

Table B.4.2
Average Full Costs for Service Installations at LADWP

Cost Element	Total Cost+ Conventional Materials	Total Cost+ Non-leaded Materials
Labor	$1,190	$1,190
Materials (293)	254	293
Equipment	195	195
Construction Support	251	251
Miscellaneous^	52	52
Total Service Line Cost	$1,942	$1,981
Relative service cost line w/ non-lead:		102%

* Data from 827 new service line installations

\+ Direct costs with overheads applied

^ Other cost elements, not disaggregated

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

REMOVAL OF LEAD GOOSENECKS

Until 1925, the LADWP used lead goosenecks to connect the service line to the main. The gooseneck is a short section of lead pipe that is flexible and break-resistant when the water main and service line shift due to ground settlement or an earthquake. All lead goosenecks have now been replaced with copper tube, bent into an "S" form. Because the S-form copper tube can flex or extend without failure, it takes the functional place of the gooseneck regarding settlement or earthquake motion.

SUMMARY

LADWP has implemented a No-Lead Brass Program to change out its leaded brass parts with components made using both Federalloy for curb valves, meter tailpieces, etc. (version 836 with a 0.1% maximum lead content) and SeBilloy II for meters (a.k.a. Envirobrass® with a 0.25% maximum lead content). They intend to replace all meters (~700,000) by 2016, with an annual replacement goal of 40,000 meters. There is little documented information on the material performance of non-leaded components that have been installed in the field, however limited information indicates no observed differences in structural performance. Costs of non-leaded components are currently higher than their leaded counterparts (20% - 30%), but when material costs are evaluated in perspective to the entire cost of the service installation, the overall increase in costs is significantly less (2% - 5%). As more utilities install non-leaded components and the market expands, the material cost differentials should decline.

REFERENCES

Heumann, D. 2005. LADWP No-Lead Brass Program. Email to T. Case. 9.30.05.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Louisville Water Company
Louisville, KY
AwwaRF Project 3018 Case Study

Utility Profile

Source water	Ohio River surface supply (90%) Riverbank infiltration well (10%)
Treatment	Conventional treatment Finished water disinfection with chloramines (3 mg/L final residual)
Corrosion Control Treatment	pH adjustment with quicklime with a treatment goal of pH 8.4-8.6 (Crescent Hill) and 8.0-8.2 (B.E. Payne); alkalinity adjustment with sodium carbonate with a goal of alkalinity >50 both plants.
Daily demand	127 MGD average day demand
Total customer population base	>800,000
Service line ownership	Customer-owned from property line Utility owns from main to customer's property line
Lead Service Lines	282,000 service lines Approximately 7% of service lines are lead. .
Type of replacement program	Meters, lead service lines, cement lining of lead/leadite joints: Full lead service lines replaced if found damaged or leaking; lead service connections replaced

LCR BACKGROUND

Historical Lead and Copper Rule (LCR) compliance monitoring data for the Louisville Water Company (LWC) are summarized in Table B.5.1. The data show that the LWC's 90th percentile results have consistently been below the LCR action limit of 15 μg/L. The LWC has implemented several programs to reduce household lead concentrations including a lead service line replacement program, a meter replacement program, and a cleaning and cement lining program for pipelines with lead or leadite joints.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table B.5.1
LCR Monitoring Results

	Monitoring Period 1996	 1999	 2003
90th percentile (µg/L)	6.5	4.5	5.0

LEAD SERVICE LINE REPLACEMENT PROGRAM

The LWC discontinued the use of lead service lines after 1937 when they began installing copper service lines. Up through the early 1970s, LWC would routinely repair leaking lead services. After this time, lead services requiring repair or lead services that were uncovered during repair of main leaks/breaks or other maintenance activities were routinely renewed.

The LWC initiated a main replacement program in the 1980s targeting troublesome mains, the most troublesome pipe vintage being those installed between 1926 and 1931. Because these pipes also had lead services attached, lead service renewal was accomplished while the main was replaced, providing a very cost effective way to renew hundreds of lead services each year. The cost of renewing lead services with main replacement was approximately 50-70% of the cost of individual service renewals.

For several years, the LWC has maintained a proactive lead service renewal strategy. LWC's goal to remove lead services has always been more proactive than reactive to governmental regulations. It became clear early on that lead services would eventually need to be removed and the LWC has tried to complete this work in a steady, cost-effective manner by establishing individual lead service replacement projects on a block by block basis. These service renewals are typically bundled in projects that include 50-200 services to achieve an economy of scale.

The LWC generally replaces lead goosenecks when the service lines are renewed, as they do not have a special program to target lead "goosenecks". The LWC did find that "goosenecks" were a prominent cause of service lines freezing on both copper and lead lines, especially after a very severe winter several years ago.

As of September 2005, Louisville has replaced 52,000 of 72,000 (72%) lead service lines with copper service lines. The LWC expects to replace the remaining 20,000 lead service lines by year 2015. The lead service line replacement program addresses the utility owned portion of the service line from the main to the customer property line including the meter. The prioritization of lead service line replacements is listed below:

1. If a lead service line is leaking, it is replaced with a copper service line.
2. If a customer requests a water sample be tested for lead and the result is high or if the customer is concerned, the lead service line is replaced.
3. If the utility is replacing the adjoining water main, lead service lines will be replaced.
4. The utility may identify a particular neighborhood or portion of the distribution system to replace all lead service lines.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Historical Water Quality Monitoring

In 1994, the LWC conducted water quality monitoring immediately after a lead service renewal and found that elevated lead levels were present (Coombs 2005). The lead monitoring results, summarized in Figure B.5.1, included lead testing on samples taken immediately after renewal for a period of 60 minutes. Lead testing was performed on filtered and unfiltered samples, from both forward (normal) flushing into the residence, and backflushing (from residence to meter).

The forward flushed water with filtering yielded samples with less than 5 ppb lead at all time intervals tested. The back flushed water with filtering had an initial concentration in excess of 250 ppb. The lead concentration for this situation quickly dropped below the lead action level (15 ppb) after only 1 minute of flushing. The unfiltered water that was forward flushed required over 15 minutes of flushing to reduce the lead concentration below the action level, and over 35 minutes were required to reduce the lead concentration for unfiltered water samples that were backflushed.

Based on these and other sampling and test results, the current LWC procedure is to continue flushing (forward) for a minimum of 60 minutes immediately following a lead service renewal. The forward flushing is less cumbersome with less impact on the customer. The preferred outlet for flushing is the customer's outside spigot, but internal flushing is also utilized for customers with non-functioning exterior spigots.

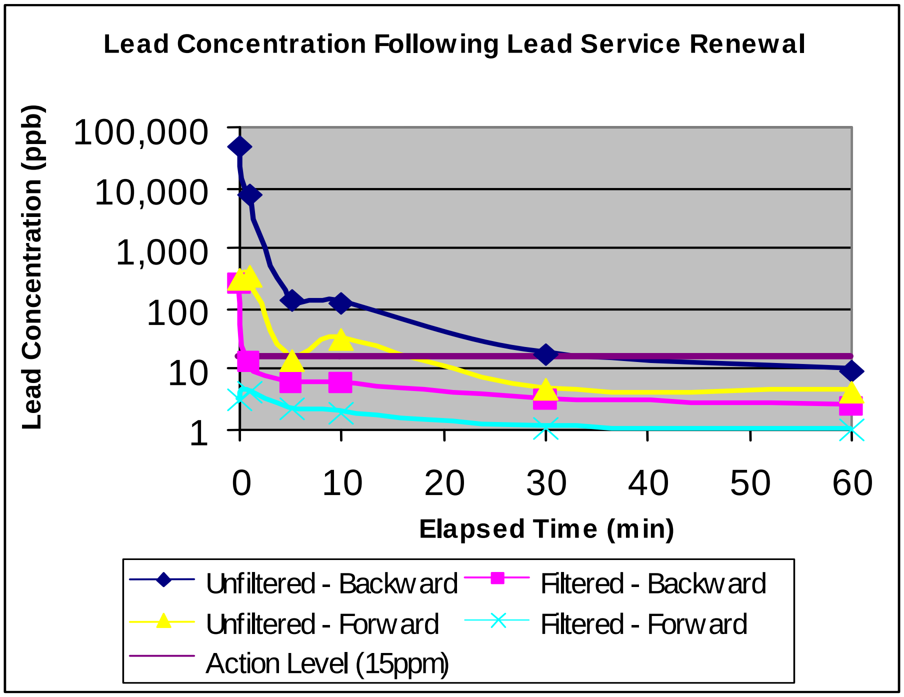


Figure B.5.1 Lead Concentration Following Lead Service Renewal

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Current Lead Service Renewal Project

In 2005, the LWC targeted lead services on Samuel Street (Dandridge Avenue to Texas Avenue) as part of the Capital Improvement Program. This program affected up to 90 residential customers that may have lead service lines. This project has been completed.

As part of this program, the LWC performed water sampling at 4 homes to determine the contribution of faucet fixtures and household pipes and/or solder to the lead concentration in tap water. Multiple samples of water were obtained before, during, and after the lead service renewal.

For a period of days prior to the start of the customer's lead service renewal, four first-draw water samples were obtained from the customer's tap in accordance with established LWC procedures. Two of these "first-draw" samples were collected after a 3 minute flush. The water was tested for lead content using both filtered and unfiltered test samples. Lead monitoring results are summarized in Table B.5.2. Additional information such as the approximate period of "no water usage", water temperature, pH, and chlorine content was determined at the time of sampling.

Immediately prior to the lead service renewal, the water service was disconnected at the meter and drained. The "drained" service line remained disconnected for a period of hours to simulate a water outage resulting from a water main break repair or other short-term maintenance activity. The service was then reconnected, filled and pressurized. Water samples were obtained at 0, 2, 4, 8, 15, 30, 45 and 60 minutes after the service was reconnected. Similar to the "first-draw" samples, the water was tested for lead content using both filtered and unfiltered test samples. The meter was once again removed and the lead service renewed in accordance with LWC standards. Where possible, the existing lead line was "pulled" out and examined, and notes were made of the material found at the property line. Once the renewal was complete, the service was once again filled and pressurized. Samples were taken at 0, 2, 4, 6, 8, 10, 15, 20, 25, 30, 40, 50 and 60 minutes. The water was analyzed using filtered and unfiltered test samples. Lead monitoring results for each of the four homes are presented in Figures B.5.2 through B.5.5. The graphs plot the lead content in the water for four different situations. The "before" concentrations were the samples obtained after the service shut-down and re-connection but before the lead service was renewed. The "after" samples were taken after the lead service was renewed during specific time intervals during the service line flushing. Testing was performed on filtered and unfiltered samples.

For a period of days following the lead service renewal, four first-draw water samples were obtained from the customer's tap in accordance with established LWC procedures. The water was tested for lead content using both filtered and unfiltered test samples. Lead monitoring results are summarized in Table B.5.2. Additional information such as the approximate period of "no water usage", water temperature, pH, and chlorine content was collected at the time of sampling.

Table B.5.2
First Draw Lead Samples Before and After Lead Service Renewals

Location	Date	Days Before/After Lead Service Renewal	First Out Total (ppb)	First Out Flushed Total (ppb)	First Out Filtered (ppb)	First Out Flushed Filtered (ppb)
1003 Samuel Street	5/13/05	7 Before	8.9	28	N/A	N/A
	5/17/05	3 Before	8.2	10	4.8	4.0
	5/18/05	2 Before	5.9	35	2.2	24
	5/19/05	1 Before	4.2	4.7	2.8	1.6
	5/24/05	4 After	5.1	< 0.5	2.3	< 0.5
	5/25/05	5 After	3.5	0.6	1.7	< 0.5
	5/26/05	6 After	3.8	< 0.5	1.4	< 0.5
	5/30/05	10 After	3.7	0.8	1.5	< 0.5
1020 Samuel Street	5/17/05	8 Before	1.4	1.8	< 0.5	< 0.5
	5/22/05	3 Before	3.3	0.8	< 0.5	< 0.5
	5/23/05	2 Before	2.2	1.0	< 0.5	< 0.5
	5/24/05	1 Before	1.7	1.3	1.0	0.8
	6/2/05	8 After	4.9	3.2	< 0.5	< 0.5
	6/3/05	9 After	3.2	1.1	< 0.5	< 0.5
	6//6/05	12 After	2.8	< 0.5	< 0.5	< 0.5
	6/10/05	16 After	5.9	2.0	< 0.5	< 0.5
1027 Samuel Street	5/13/05	18 Before	5.0	6.7	N/A	N/A
	5/14/05	17 Before	6.5	7.9	3.3	1.0
	5/15/05	16 Before	5.9	8.1	4.1	3.5
	5/16/05	15 Before	6.2	7.8	4.2	5.8
	6/2/05	2 After	14	2.3	3.8	1.0
	6/3/05	3 After	4.8	< 0.5	2.1	< 0.5
	6/4/05	4 After	4.4	0.9	2.3	< 0.5
	6/5/05	5 After	3.4	5.1	2.4	3.8
1112 Samuel Street	N/A	N/A	7.6	12.0	4.2	5.6
	5/26/05	26 Before	8.9	301	0.9	0.6
	5/29/05	21 Before	8.3	5.4	4.4	0.8
	5/30/05	20 Before	3.0	3.5	0.7	< 0.5
	N/A	N/A	5.7	1.5	< 0.5	< 0.5
	N/A	N/A	1.5	1.0	< 0.5	< 0.5
	6/23/05	2 After	2.2	8.0	< 0.5	< 0.5
	6/24/05	3 After	< 0.5	0.7	< 0.5	< 0.5

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

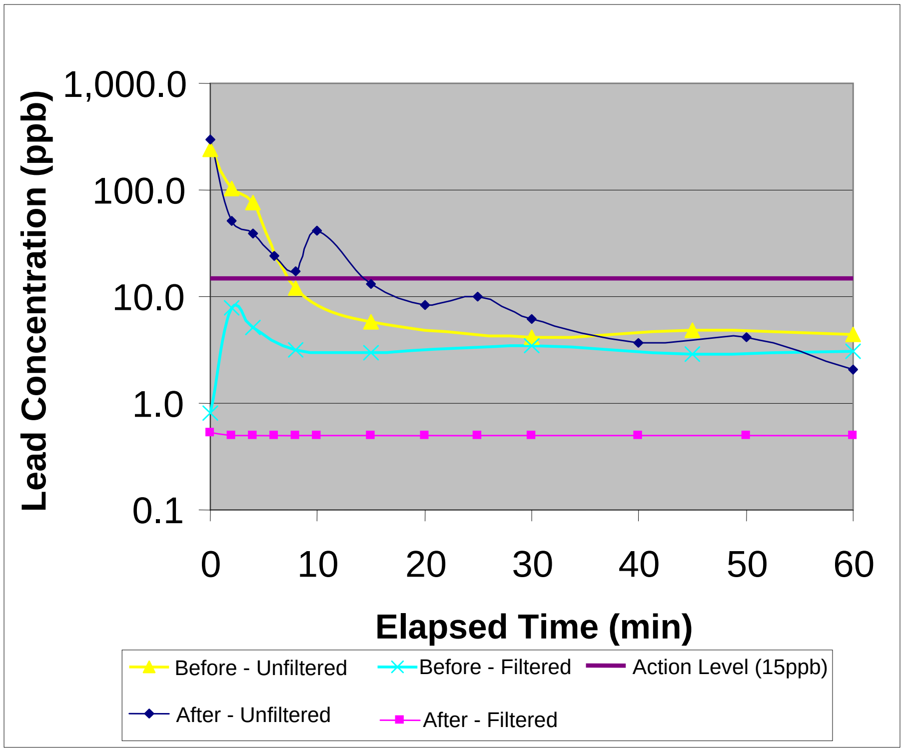


Figure B.5.2 1003 Samuel Street - Lead Concentration

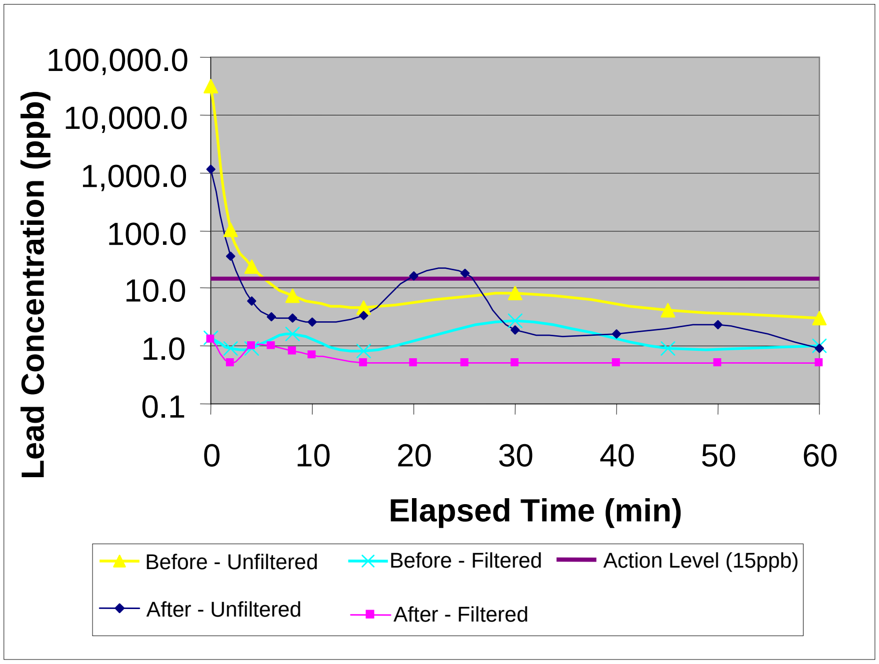


Figure B.5.3 1112 Samuel Street - Lead Concentration

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

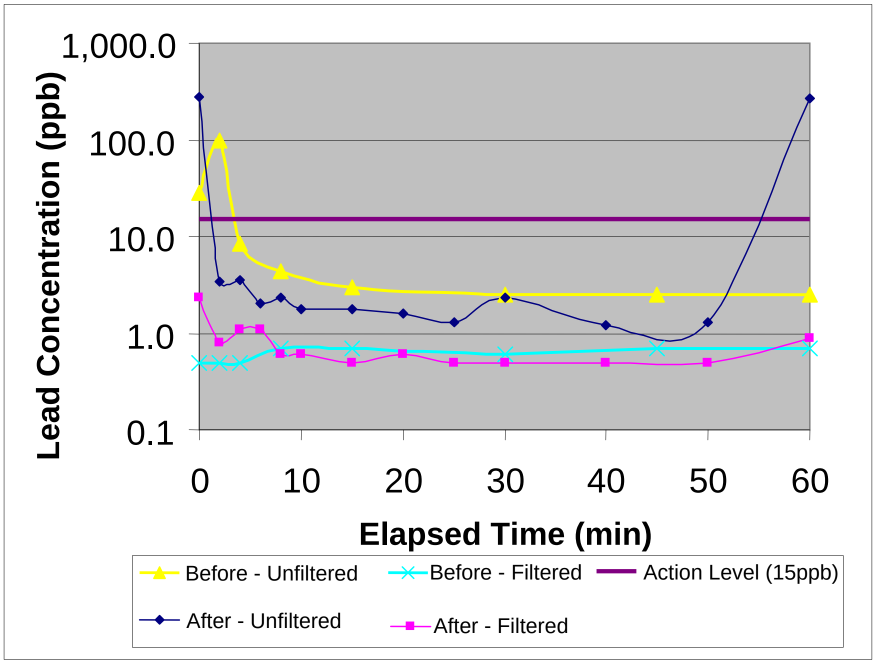


Figure B.5.4 1020 Samuel Street - Lead Concentration

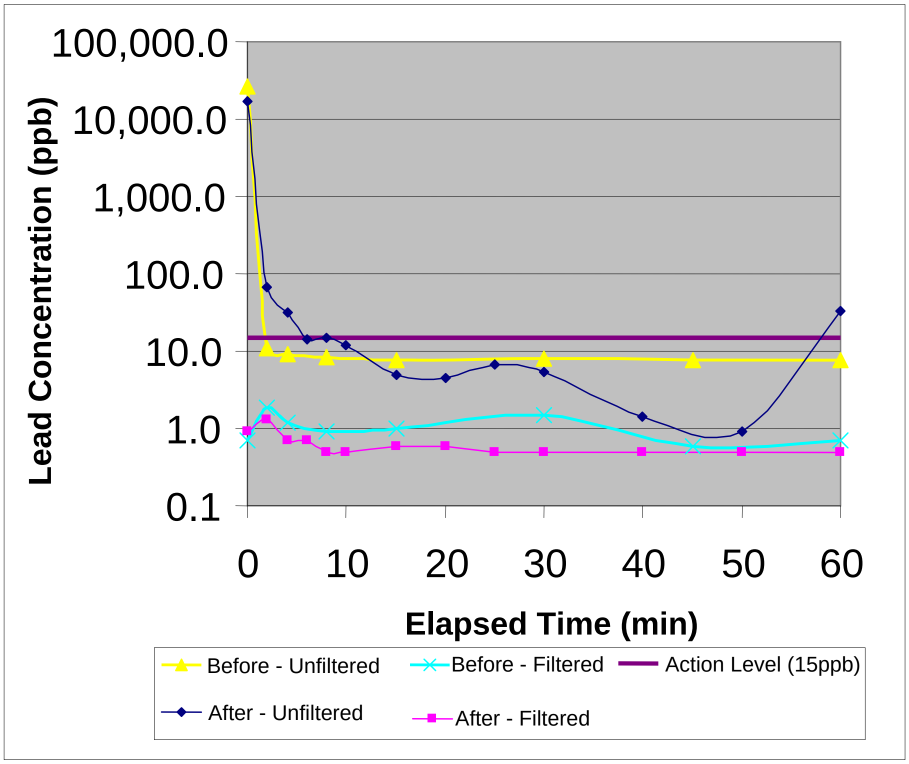


Figure B.5.5 1027 Samuel Street - Lead Concentration

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Figures B.5.4 and B.5.5 illustrate how the lead concentration in unfiltered samples from 1020 and 1027 Samuel Street started to rise 50 minutes after the lead service renewal. The filtered samples from the same time frame contained low lead concentrations (0.9 ppb at 1020 Samuel Street and <0.5 ppb at 1027 Samuel Street for the 60 minute sample). LWC has generally associated "spikes" in total lead with physical changes in the water flow (turn-off and turn-on), so it may be plausible that the high total lead content may have resulted from particles dislodged from flow changes inside the residence or from disturbances resulting from nearby lead service renewal work. The water samples were obtained from the outside spigots and flow was continuously maintained at the spigot throughout the sampling period.

The lead concentrations taken as "first draw" samples after the lead service renewal were all less than 6 ppb (total lead) at the four renewal locations with one exception (data summarized in Table B.5.2). At 1027 Samuel Street, one first draw sample collected two days after the renewal had a total lead concentration of 14 ppb. Flushing for three minutes prior to taking the "first draw after renewal" sample tended to decrease the total lead content in almost all samples.

The dissolved lead concentration for the first out filtered samples taken after the service renewal was generally less than 4.0 ppb (data summarized in Table B.5.2). Flushing for three minutes prior to securing the samples reduced the dissolved lead content to less than detectable limits (< 0.5) for all but two samples. At 1027 Samuel Street, dissolved lead concentrations of 1.0 and 3.8 ppb were obtained for filtered first draw samples taken after the service was renewed.

METER REPLACEMENT PROGRAM

Louisville implemented its meter replacement program through incorporation of material specifications associated with multi-year contracts for the annual replacement of meters and fittings. Through the specifications approach Louisville included a “no lead” provision that requires the installation of meters and fittings whose components, individually, do not exceed a lead content of 0.25%.

In the year 2000, the LWC revised its meter specifications to require a lead-free designation with NSF 61 certification (Russell 2005). The NSF 61 requirements would be open to Envirobrass® "EB2" that is a totally lead free product to compete with other brass products such as "XL" that is leached and tested for final processing. An excerpt from the meter specification follows (Louisville Water Company 2005):

“*1. Strainer and Meter Housing/Casing/Covers - Meter housings, casings, and covers shall be constructed of lead-free bronze, preferably certified as ANSI/NSF Standard 61 LEACH Test compliant. The lead-free bronze shall be corrosion resistant, shall not be subject to dezincification and shall have mechanical properties, which are suitable to retain structural integrity for 25 years from date of shipment.”*

CEMENT LINING OF LEAD AND LEADITE JOINTS

The main rehabilitation program (cleaning and cement lining) started in the early 1980s at the same time that the LWC started the main replacement program. The primary target of the main rehabilitation program has been unlined cast iron mains installed from 1860 to 1931 that still maintained structural integrity as exhibited by a lack of break repairs, and which would meet hydraulic needs when clean and lined. From 1980 to 2005, over 280 miles of unlined cast iron pipe has been cleaned and lined with cement mortar. Assuming that all joints in this unlined cast iron pipe were either lead or leadite, the LWC has placed a cement lining over approximately 75,000-80,000 joints during this time frame.

Lining over lead and leadite joints was not the primary goal of the program but a beneficial side effect. Therefore, it is difficult to determine a cost for lining over the joints individually. Most of the distribution piping was cleaned and lined at a cost of $25-$35 per linear foot. Transmission mains were cleaned and lined in the early years at a cost considerably higher than this value. The relatively low cost for the distribution work was achieved by use of an annual contract and large project areas. More recent cost data from areas surrounding Louisville indicate that the cost of cleaning and cement lining may be significantly higher.

Water quality testing has been routinely performed on all mains that have been cleaned and lined mains as part of the project's acceptance phase. LWC routinely samples relined water mains for chlorine, turbidity, pH, and bacteria. Testing for pH is important to ensure sufficient flushing has occurred to minimize alkalinity from the freshly applied cement. Lead sampling was not performed as part of this acceptance testing.

SUMMARY

The LWC has implemented several programs to reduce household lead concentrations including a lead service line replacement program, a meter replacement program, and a cleaning and cement lining program for pipelines with lead or leadite joints. The lead service renewal program was conducted in association with their main replacement program in the 1980s. The lead service line was replaced while the main was replaced, providing a very cost effective way to renew hundreds of lead services each year, at a cost estimated to be approximately 50-70% of the cost of individual service renewals. LWC's lead service line replacement program addresses the utility owned portion of the service line from the main to the customer property line including the meter.

To address the lead content of meters, Louisville included a "no lead" provision in their specifications that requires the installation of meters and fittings whose components, individually, do not exceed a lead content of 0.25%. The potential impact of lead and leadite joints used in unlined cast iron water mains was addressed through a main rehabilitation program. This program was designed to clean unlined cast iron pipe and line it with cement mortar. While covering lead and leadite joints was not the primary goal of the program, it was a beneficial side effect.

Louisville's "no lead" meter, fitting and lead service line replacement programs are currently scheduled for continuance with the ultimate goal of removing all sources of lead up to premise piping. The increased costs of the program are considered acceptable. To date, Louisville considers the programs to be a success at protecting public health with inconsequential additional financial burden.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

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Utility Profile

Source water	Groundwater (100%) – 24 wells
Treatment	Chlorine and fluoride addition at each well
Corrosion Control Treatment	None. Full Lead Service Line Replacement Program Implemented to meet requirements of the LCR
Daily demand	32 MGD average day demand
Service line ownership	Customer-owned from curb-stop to building Utility owns from main to curb-stop
Lead Service Lines	1574 utility owned lead service lines 1358 customer owned lead service lines
Type of replacement program	Full Lead Service Line Replacement: Full lead service lines replaced as part of on-going program to meet requirements of the LCR

INTRODUCTION

Madison Water Utility provides groundwater from a deep sandstone aquifer to over 60,000 service locations. Average water use is about 32 million gallons per day (Madison Water Utility, 2006a). The water is pumped from 24 wells that range from 500 to 1130 feet deep. It is stored in 31 reservoirs and flows through about 810 miles of water main. Water treatment consists of chlorine addition to achieve 0.2 mg/L free chlorine and fluoride addition to achieve 1.1 mg/L. This chemical addition is performed at each well house.

Lead was commonly used for water service lines from 1882, the inception of Madison Water Utility, through 1927. Eleven thousand lead water service lines were installed during this time period. From the 1930s to 1960s, the Utility began replacing lead services on a small scale. Some lead services were replaced with copper when they leaked or when customers reported a low flow problem. During the 1970s, the Utility began replacing lead services when streets were reconstructed. In the late 1980s, Utility crews began replacing lead services during street resurfacing jobs. (Madison Water Utility, 2006b)

Hersey water meters, some of which used lead weights, were used from about the 1940s through the 1960s. The last of the lead-weight Hersey meters were replaced sometime in the 1990s. In about 2004, Madison Water Utility switched to non-leaded "EnviroBrass®" meters from Badger Meter, Inc. Older meters are still refurbished and reused, but when a meter is replaced after a lead service replacement the new meter is always non-leaded. Brass Mueller corps and curb stops used in the Madison Water Utility distribution system contain about 5% lead (Madison Water Utility, 2006b).

HISTORY OF LEAD CORROSION CONTROL IN MADISON

Corrosion control investigations were initiated after Lead and Copper Rule sampling in 1992 indicated a ninetieth percentile lead concentration of 16 µg/L. The recommendations from the corrosion control studies were to skip the chemical alteration of the water as prescribed by the Lead and Copper Rule and move directly to a control step allowed in the Rule only if chemical treatment fails. That control step is the replacement of lead water service lines. The arguments for making this bold step were:

- Because of the water's potential for precipitating calcium, pH adjustment was not chemically viable.
- Because the water comes from twenty-four distinct sources with no common treatment or storage facilities, alkalinity adjustment was not economically viable.
- Sodium silicate did not show any benefit in jar tests. Plus, there was little information on the use of sodium silicates.
- Polyphosphates increased the lead concentration in the water.
- Orthophosphates successfully lowered the lead levels. (Cantor, et. al., 2000), however, the Madison Metropolitan Sewage District had recently completed the installation of a biological phosphorus removal system that depended on a particular ratio of organic matter to phosphorus. If phosphorus was to be added to the drinking water, the removal system would not work properly and a chemical phosphorus removal system would need to be added. In addition, the water that would runoff directly to the lakes would carry phosphorus with it.

The Wisconsin Department of Natural Resources (WDNR) agreed that removing lead water service lines as a means of corrosion control was the only reasonable option available and further required that Madison achieve "optimal corrosion control" where the ninetieth percentile lead concentration is to be 5 µg/L.

ESTABLISHING COMPLETE LEAD SERVICE LINE REPLACEMENT

In order to achieve the goal of 5 µg/L ninetieth percentile lead concentration, however, the WDNR required the utility to remove the complete lead service line. This presented a problem in that the water utility owns the water service line up to the curb stop at a private building and the property owner owns the service line from the curb stop to the building. Property owners would have to be encouraged to replace their portion of the service line and the cost of doing so would need to be addressed.

These were the considerations taken into account by the Madison Water Utility and the Madison Common Council. They concluded that replacement of the customer side of lead service lines in the City was of benefit not only to each individual customer, but to the utility and community as a whole in meeting state and federal drinking water standards and avoiding the cost to all customers of adding corrosion control chemicals to the water system indefinitely. The lead service line replacements would also avoid the cost and environmental impact of adding phosphorus to wastewater streams. Consequently, the City established a requirement for customers to replace their lead water service lines and a program whereby they would be reimbursed for half the cost of replacing those lines up to $1000 reimbursement per property.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

The utility, for which rates are regulated by the Public Service Commission of Wisconsin (PSCW), requested that the PSCW include half the cost of replacing customer lead service lines in its rate base. The PSCW denied the request, rejecting the utility's arguments about the benefits to the utility and community and expressing the opinion that all water customers should not be burdened with any cost for replacing customer-owned service lines. Subsequently, the Common Council approved a plan to place half the cost of replacing customer lead service lines on sewer rates, for which the PSCW did not have regulatory jurisdiction. The City justified this by showing a substantial avoided cost to sewer customers by implementing a complete lead service replacement program as opposed to adding corrosion control chemicals to drinking water, which would need to be removed at the wastewater treatment plant. Madison approved a complete lead service replacement program in February 2000, with a goal of replacing all lead water service lines in the City by 2011.

On January 1, 2001, the initiation of the complete lead service line replacement program, there were approximately 6,000 existing Water Utility side services and 5,000 customer-side services. As of December 31, 2005, the Utility has replaced or cut off about 4,307 Utility-side lead services or 72%, while customers have replaced 3,633 lead services or 73%. There are 1574 utility-owned lines and 1358 customer-owned lines remaining in the distribution system. All services are now scheduled to be removed by the end of 2009, two years ahead of the original schedule (Madison Water Utility, 2006b).

COSTS OF LEAD SERVICE LINE REPLACEMENT

Madison Water Utility tracks lead service line replacement costs for those services replaced by Utility crews through the lead service replacement work order. Any replacements done by city contract during water main replacement jobs are not included in these numbers. Because of this, the total number of lead service line replacements reported here will not equal the number actually replaced. Nevertheless, the costs do reflect the unit cost to replace a lead service line. As shown in the Table B.6.1, the costs to replace the Utility-side services have averaged $2212 per service line over the past eleven years. The replacement cost per line has ranged from $1798 in 1995 to $2751 in 2005. (Madison Water Utility, 2006b)

On the Property Owner-side service, the property owner is reimbursed for 50% of the replacement costs up to $1000. The average reimbursement to property owners has been $663.88. This implies that the average property owner-side replacement cost is $1327.76. However, this number does not account for replacements that are over $2000 since amounts over $2000 are not reported to the Utility for reimbursement. Reimbursements made since December 2000 are calculated in Table B.6.1 and Table B.6.2 lists the customer side replacement costs.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table B.6.1
Madison Water Utility: Utility-side Lead Service Line Replacement Costs

Year	Number of Lead Service Line Replacements	Total Cost	Unit Cost
1995	226	$406,276	$1,798
1996	202	$341,633	$1,691
1997	239	$445,960	$1,866
1998	234	$459,946	$1,966
1999	352	$679,842	$1,931
2000	309	$601,995	$1,948
2001	570	$1,128,827	$1,980
2002	528	$1,266,050	$2,398
2003	553	$1,304,975	$2,360
2004	547	$1,399,144	$2,558
2005	528	$1,452,498	$2,751
Total	4,288	$9,487,146	$2,212

Table B.6.2
Madison Water Utility: Customer-side Lead Service Line Replacement Costs

Total Dollars Reimbursed	$2,754,420.93
Number of Reimbursements	4,149
Average Reimbursement Paid	$663.88
Average Total cost for Customer-side Lead Service Line Replacement	*$1327.76

*Note: This number does not account for replacements that are over $2000 since amounts over $2000 are not reported to the Utility

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

FOLLOW-UP MONITORING ON LEAD SERVICE LINE REPLACEMENT

In 2003, Madison Water Utility initiated a special project to assess the success of the lead line replacement program in terms of achieving optimal corrosion control. The study found that total lead concentration at a residence with a lead service line in Madison is typically seen to be erratic (Figure B.6.1). After lead line replacement, the erratic behavior continues (Figure B.6.2). By comparing Figures B.6.2 and B.6.3, it is seen that the erratic lead concentration is from lead particulate matter dislodging from pipe walls and arbitrarily becoming entrained in water samples. At the same time, dissolved lead concentration, which represents uniform corrosion, is lowered with lead service line replacement. At this time in Madison, the ninetieth percentile dissolved lead sampling results are at the desired goal of 5 µg/L (Figure B.6.3). The data suggest that the lead laden particulate matter is flushed out over several years after lead materials are removed from the plumbing system and a total lead concentration of 5 µg/L is eventually achieved (Figure B.6.2). (Cantor, 2006)

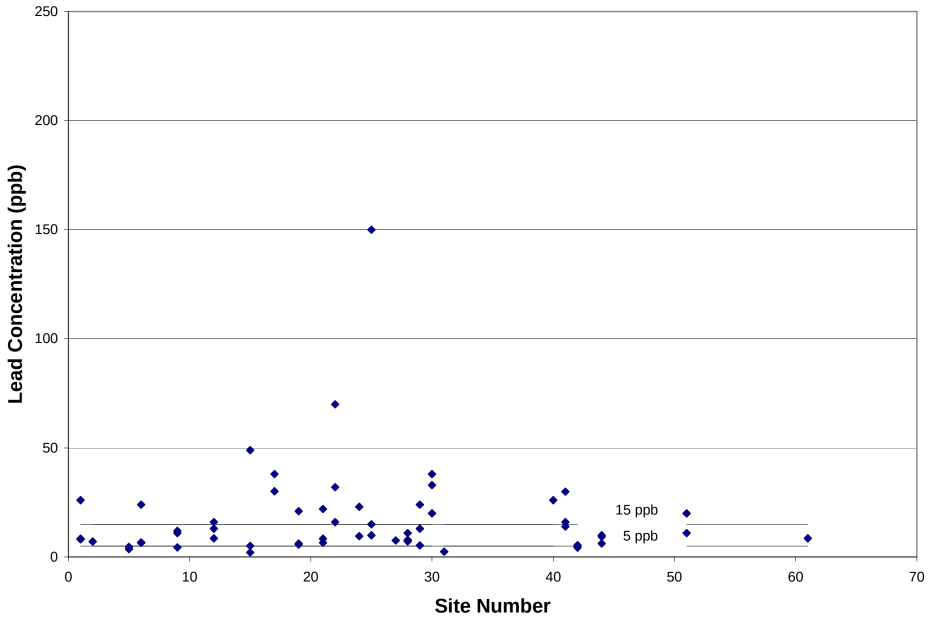

Figure B.6.1 Total (Particulate + Dissolved) Lead Concentration at Sites Before Full Lead Service Line Replacement

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

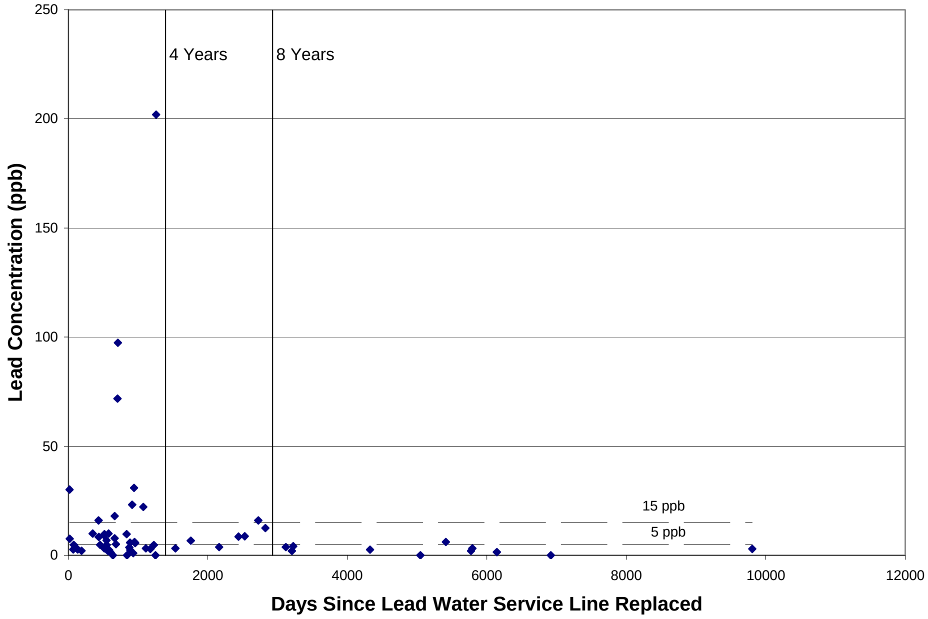

Figure B.6.2 Total (Particulate + Dissolved) Lead Concentration vs. Time Since Full Lead Service Line Replacement

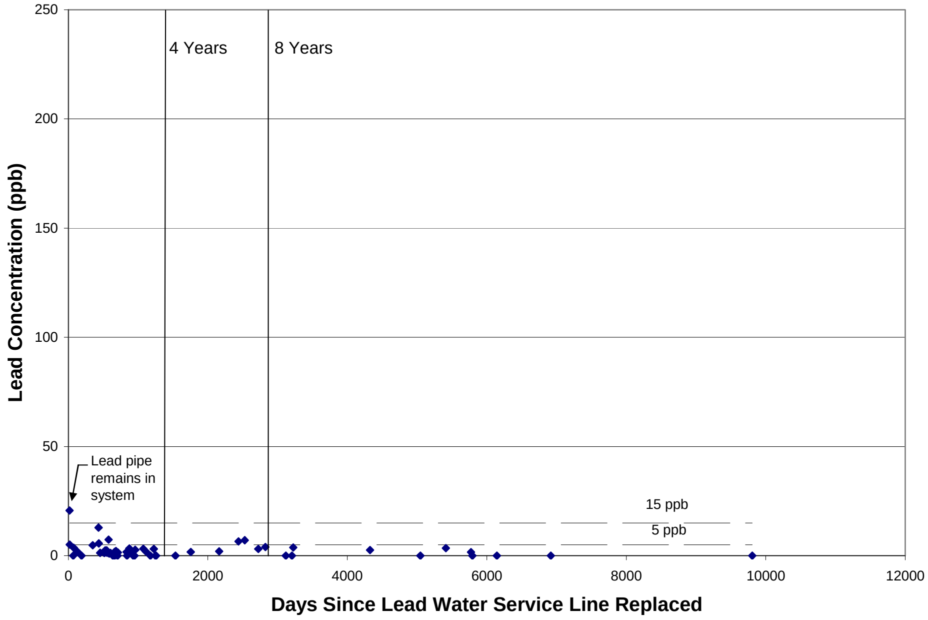

Figure B.6.3 Dissolved Lead Concentration vs. Time Since Full Lead Service Line Replacement

LEAD SERVICE PIPE SCALE EVALUATIONS

As models of lead solubility show, the DIC and pH of water determine what lead compounds will predominate, and the solubility of the predominant lead compound determines

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

the concentration of lead in the water (Schock, 1980). At a high DIC concentration such as in Madison's water, there is ambiguity in the solubility model as to how corrosive the water is. One research study reported that in high DIC water, a more soluble compound of lead (hydrocerussite) is often found where a less soluble compound (cerussite) is predicted (Sheiham and Jackson, 1981).

With that ambiguity in mind, a lead water service pipe excavated in Madison was sent to Michael Schock, US Environmental Protection Agency Research Chemist, for examination in 2001. He reported that on top of a familiar lead carbonate compound (cerussite), on the pipe wall, there was a predominance of yet another lead compound, lead dioxide (plattnerite), which was not included in the existing solubility model. He explained that this relatively insoluble lead compound would signify water with very low aggressiveness. Mr. Schock published this and similar findings noting that lead concentrations found in Madison are more than a factor of 10 below the expected lead concentrations from the DIC-based solubility model (Lytle and Schock, 2005).

Three more lead pipes were sent to Michael Schock for analysis in May and September 2005. These three pipes also had cerussite overlaid by plattnerite on the pipe wall, but there was an additional factor. A scale layer of manganese and iron compounds was observed on the pipe wall. Mr. Schock reported (Schock, et. al., 2006): "Since lead compounds are intermingled with the manganese and iron scale layers, and it is probable that lead ions are sorbed to the oxyhydroxide surfaces, destabilization of these Mn/Fe deposits could release microparticles intermittently." Indeed, past lead monitoring studies in Madison have shown lead in the drinking water to be mostly in particulate form.

FUTURE MONITORING

The results of the lead line replacement monitoring study were discussed with WDNR. Madison Water Utility proposed that more monitoring be done to substantiate the premise that particulate lead decreases over time after a complete lead service line is replaced and a concentration of 5 µg/L of total lead or below is ultimately achieved. The WDNR stated that Madison Water Utility compliance with the Lead and Copper Rule would be based on the results of the continued monitoring along with the standard Lead and Copper Rule sampling results presented at the end of the lead water service line replacement program in 2011. If the ninetieth percentile lead level for total lead concentration is over 15 µg/L at that time but the monitoring data shows that particulate lead decreases over time, then Madison Water Utility will be deemed in compliance.

SUMMARY

The Madison Water Utility has undertaken a full lead service line replacement program to meet the requirements of the Lead and Copper Rule, with a goal of replacing all lead service lines in the City by 2011. Since the customer has authority of the service line from the curb-stop to the building, the Madison Common Council approved a plan to place half the cost of replacing customer lead service lines on sewer rates. This decision was justified by showing a substantial avoided cost to sewer customers by implementing a complete lead service replacement program as opposed to adding corrosion control chemicals to drinking water, which would need to be removed at the wastewater treatment plant.

Water quality data collected to assess the success of the lead line replacement program suggests that dissolved lead concentrations are lower after full lead service line replacement, but total lead concentration are erratic, and continue to be erratic for several years. Evaluation of the scale present on Madison lead service pipes indicates the presence of lead compounds intermingled with manganese and iron scale layers, resulting in destabilization of these Mn/Fe deposits and intermittent release of microparticles.

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Lytle, D.A. and M.R. Schock. 2005. "Formation of Pb(IV) Oxides in Chlorinated Water," *Journal of the American Water Works Association* (97:11:102).

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- Doug De Master, Engineering Systems and Mapping Engineer
- Dan Rodefeld, Field Supervisor
- Robin Piper, Accountant
- Tony Mazzara, Water Meter Mechanic Leadworker
- Ken Key, Customer Service Manager

Schock, M.R. 1980. "Response of Lead Solubility to Dissolved Carbonate in Drinking Water," *Journal of the American Water Works Association* (72:12:695).

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Sheiham, I. and P.J. Jackson. 1981. "The Scientific Basis for Control of Lead in Drinking Water by Water Treatment," *Journal of the Institute of Water Engineers and Scientists* (35:6:491).

Utility Profile

Source water	Surface: Chickahominy River (primary) Diascund Creek, Little Creek, Skiffe's Creek, Lee Hall, and Harwood's Mill reservoirs (secondary) Groundwater: Deep brackish wells at Lee Hall
Surface Treatment	Conventional filtration, fluoridation, pH adjustment, corrosion control, chlorine disinfection and secondary chloramination.
Groundwater Treatment	Reverse osmosis and blending with Lee Hall treated surface water
Corrosion control treatment	Zinc orthophosphate addition
Daily demand	45-50 MGD
Total customer population base	400,000
Type of replacement program	Meter Replacement

INTRODUCTION

Newport News replaces approximately 8,500 meters annually through their meter replacement program plus incidental replacements that happen as a result of other types of work. In 2004, LCR compliance monitoring results showed a 90th percentile lead level of <1 μg/L. Newport News normally purchases meters from the low bidder that meets the specification without taking any exceptions. For several years, the Newport News' meter supplier provided the new Envirobrass® meter casings at no additional cost under the current year meter contract. This meter supplier had stopped using meter casings that contained lead. In September 2004, Newport News revised its meter specification by asking for two sets of pricing (with lead content/no lead content) to determine if a cost factor would be involved in the decision to use no-lead meters. The 2004 bid results showed that the same meter supplier again had the most price-competitive bid response even with the Envirobrass® product and was awarded the meter contract for the new contract period.

The following section contains Newport News' bid documents for no-lead meters, which forms the basis of this case study to provide an example for other utilities considering use of no-lead meters.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

INVITATION FOR BIDS

IFB #2005- 46457 -0224
September 2, 2004

City of Newport News, Dept. of Purchasing
2400 Washington Avenue, 4th Floor, City Hall
Newport News, VA 23607

Phone: (757) 926-8721/ Fax: (757) 926-8038
www.nngov.com/purchase/index.htm

Water Meters

Sealed bids, subject to the conditions and instructions contained herein, will be received at the above office of the Purchasing Agent, 4th Floor, City Hall, 2400 Washington Avenue, Newport News, Virginia, until the due date and hour shown below (local prevailing time), and then publicly opened, for furnishing the following described equipment, materials, and/or services, for delivery and/or performance F.O.B. NEWPORT NEWS, VIRGINIA.

SCOPE: To establish a renewable term contract for the purchase of Water Meters for the Department of Public Utilities.

BID DUE: **3:00 PM, September 21, 2004**

Contract Officer: ____
Greg Smith, CPPB, Senior Buyer, gsmith@nngov.com

*****AN ORIGINAL AND ONE (1) COPY OF YOUR SUBMITTAL IS REQUESTED*****

In compliance with this Invitation for Bids, and subject to all the conditions thereof, the undersigned offers, if this bid is accepted within (60) calendar days from the date of the opening, to furnish any or all of the items and/or services upon which prices are quoted, at the price set opposite each item, to be delivered at the time and place specified herein. The undersigned certifies he has read, understands, and agrees to all terms, conditions, and requirements of this bid, and is authorized to contract on behalf of firm named below.

This public body does not discriminate against faith based organizations

Company Name: ____

Address: ____

City/State/Zip: ____

Telephone: ____________________ Fax No.:______________________ E-Mail: _________________

Fed. Tax ID (or Social Security #): _____ ____ ____ ____ ____ ____ ____ ____ ____

Print Name: ____ Title:________________________

Signature: ____ Date:________________________

This form must be signed. All signatures must be original and not photocopies

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

CONDITIONS AND INSTRUCTIONS

1. All bids shall be submitted on and in accordance with this form. If more space is required to furnish a description of the commodities and/or services offered or delivery terms, the bidder may attach a letter hereto that will be made a part of the bid. All bids shall be submitted sealed, plainly marked showing the bid number, date and time.

2. Bids and amendments thereto, if received by the Purchasing Department after the date and time specified for bid opening, will not be considered. It will be the responsibility of the bidder to see that their bid is received by the Purchasing Department by the specified time and date. There will be no exceptions. Date of postmark will not be considered. Telephone, facsimile, electronic and verbal bids will not be accepted. Prices or changes shown on the outside of an envelope will not be acceptable.

3. Prices shall be stated in units of quantity specified. No additional charges shall be passed to the City , including any applicable taxes, delivery or fuel surcharges. Prices quoted shall be the final cost to the City.

4. The time of proposed delivery must be stated in definite terms. If time of delivery for different commodities varies, the bidder shall so state.

5. Samples, when requested, must be furnished free of expense, and upon request, if not destroyed, will be returned at the bidder's risk and expense.

6. In case of error in the extension of prices, the unit price shall govern.

7. Unless qualified by the provision "NO SUBSTITUTE", the use of the name of the manufacturer, brand make or catalog designation in specifying an item does not restrict bidders to the manufacturer, brand, make or catalog designation identification. This is used simply to indicate the character, quality and/or performance equivalence of the commodity desired. The commodity on which bids are submitted must be of such character, quality and/or performance equivalence that it will serve as that specified. In submitting bids on a commodity other than as specified, bidder shall furnish complete data and identification with respect to the alternate commodity they propose to furnish.

   Consideration will be given to bids submitted on alternate commodities to the extent that such action is deemed to serve the best interests of the City. If the bidder does not indicate that the commodity he proposes to furnish is other than specified, it will be construed to mean that the bidder proposes to furnish the exact commodity described.

8. The bidder certifies by signing this Invitation for Bid that this bid is made without prior understanding, agreement, or accord with any other person submitting a bid for the same product or service and that this bid is in all respects bona fide, fair and not the result of any act of fraud or collusion with another person engaged in the same line of business or commerce. Any false statement hereunder constitutes a felony and can result in a fine and imprisonment, as well as civil damages.

9. Award will be made to the lowest responsive and responsible bidder. The quality of the articles to be supplied, their conformity with the specifications, their suitability to the requirements, the delivery terms, qualifications and references will be taken into consideration in making an award. Length of time for delivery as well as price may be considered in awarding the bid.

   Upon making an award, or giving notice of intent to award, the City will place appropriate notice on the public bulletin board located outside of the Purchasing Department at City Hall. Notice of award may also appear on the Purchasing Website:

   www.newport-news.va.us/purchase/index.htm. or www.demandstar.com

10. The City reserves the right to award by item, groups of items or total bid; to reject any and all bids in whole or in part, and to waive any informality if it is determined to be in the best interest of the City.

11. Payment Terms:

    a) Payment terms shall be "2%-20, Net 30 days" unless otherwise stated by the bidder/offeror on this submittal form. Alternate terms may be offered by bidder/offeror for prompt payment of bills.

    b) Payment terms shall be considered in determining the low bidder/ offeror.

    c) Discount period shall be computed from the date of proper receipt of the vendor's correct invoice, or from the date of acceptable receipt of the goods/services, whichever is latest.

    d) The payment terms stated herein must appear on the vendor's invoice. Failure to comply with this requirement shall result in the invoice being returned to the vendor for correction.

    e) Late payment charges shall not exceed the allowable rate specified by the Commonwealth of Virginia Prompt Payment Act. (1% per month)

12. Receipt of your bid by the City is not to be construed as an award or an order to ship.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

13. Each bid (offer) is received with the understanding that the acceptance in writing by the City of the bidder to furnish any or all of the commodities and/or services described therein, shall constitute a contract between the bidder and the City, which shall bind the bidder on his part to furnish and deliver the articles quoted on at the prices stated and in accordance with the conditions of said accepted bid; and the City on its part to order from such contractor, except for causes beyond reasonable control; and pay for, at the agreed prices, all articles specified and delivered.

14. Any equipment delivered must be standard new and unused equipment, latest model, except as otherwise specifically stated in the bid. Where any part or the normal accessories of equipment is not described, it shall be understood that all the equipment and accessories that are usually provided in the manufacturer's stock model shall be furnished.

15. In event of default by the contractor, the City reserves the right to procure the commodities and/or services from other sources, and hold the contractor liable for any excess cost occasioned thereby.

16. Availability of Funds: A contract shall be deemed executory only to the extent of appropriations available to each department for the purchase of such articles or services. The City’s extended obligations on those contracts that envision extended funding through successive fiscal periods shall be contingent upon actual appropriations for the following years.

17. The contractor guarantees to defend and save the City, its agents and employees, harmless from liability of any nature or kind, for use of any copyright, composition, secret process, patented or unpatented invention, articles or appliances furnished or used in the performance of the contract, or which the contractor is not the patentee, assignee, or licensee.

18. The contractor shall keep himself fully informed of all Federal, State and local laws, ordinances and regulations that in any manner affect the conduct of the work. The contractor shall at all times observe and comply with all such laws, ordinances and regulations and he shall protect and indemnify the City, and its representatives against any claim or liability arising from or based on any violation of the same, whether by the contractor, his subcontractors, suppliers of materials or services, or others engaged by the contractor or the employees of any of them.

19. All prices and notations should be in ink or typewritten. Mistakes may be crossed out and corrections made in ink and must be initialed and dated in ink by the person signing the bid.

20. All bids must be signed by an authorized, responsible officer or employee having the capacity to enter contracts. Obligations assumed by such signature must be fulfilled.

21. If you do not quote, advise the City of your intent and state the reason. Otherwise your name may be removed from our mailing list.

22. By signing this bid, the bidder assigns to the City any and all rights that he may have under the antitrust laws of the United States and the Commonwealth of Virginia in any way arising from or pertaining to this bid. This provision is remedial in nature and is to be liberally construed by any court in favor of the City.

23. Appeals Procedure: Upon your request administrative appeals information will be provided which shall be used for hearing protests of a decision to award or an award, appeals from refusal to allow withdrawal of bids, appeals from disqualification, appeals for debarment or suspension, or determinations of non-responsibility and appeals from decision or disputes arising during the performance of a contract.

24. **Non-Discrimination:** During the performance of this contract, the contractor agrees as follows:

(a) He will not discriminate against any employees or applicants for employment because of race, religion, color, sex, national origin, age, disability, or any other basis prohibited by state law relating to discrimination in employment, except where one or more of these are a bona fide occupational qualification reasonable necessary to the normal operations of the contractor. The contractor agrees to post in conspicuous places available to employees and applicants for employment, notices setting forth the provisions of this non-discrimination clause.

(b) The contractor will be and state that he is an equal opportunity employer in all solicitations or advertisements for employees.

(c) Notices, advertisements and solicitations placed in accordance with federal law, rule or regulation shall be deemed sufficient for the purpose of meeting the requirements of this section.

The contractor will include the provisions of the foregoing paragraphs (a), (b) and (c) in every subcontract or purchase order of over ten thousand dollars so that the provisions will be binding upon each subcontractor or vendor.

During the performance of this contract, the contractor agrees to (i) provide a drug-free workplace for the contractor’s employees; (ii) post in conspicuous places, available to employees and applicants for employment, a statement notifying employees that the unlawful manufacture, sale, distribution, dispensation, possession, or use of a controlled substance or marijuana is prohibited in the contractor’s workplace and specifying the actions that will be taken against employees for violations of prohibition; (iii) state in all solicitations or advertisements for employees placed by or on behalf of the contractor that the contractor maintains a drug-free workplace; and (iv) include the provisions of the foregoing clauses in every subcontract or purchase order of over $10,000, so that the provisions will be binding upon each subcontractor or vendor.

For the purposes of this subsection, “A drug-free workplace” means a site for the performance of work done in connection with a specific contract awarded to a contractor in accordance with this subsection, the employees of whom are prohibited from engaging in the unlawful manufacture, sale, distribution, dispensation, possession or use of any controlled substance or marijuana during the performance of the contract.

25. **Direct contact with City departments other than Purchasing, on the subject of this bid is expressly forbidden except with the foreknowledge and permission of the Director of Purchasing or their representative.**

26. Assignment of Contract: A contract shall not be assignable by the contractor in whole or in part without the written consent of the City.

27. Applicable Law and Courts: Any purchase order/contract resulting from this solicitation shall be governed in all respects by the laws of the Commonwealth of Virginia and any litigation with respect thereto shall be brought in the courts of the Commonwealth. The contractor shall comply with applicable federal, state and local laws and regulations.

28. Bidders have the right to request withdrawal of their bids from consideration due to error by giving notice not later than two days after bids are publicly opened. Work papers showing evidence of error(s) may be required. Upon request Administrative withdrawal procedures will be provided that shall be used for that purpose.

29. If City Hall is closed for business at the time scheduled for bid opening, for whatever reasons, sealed bids will be accepted and opened on the next business day of the City, at the originally scheduled hour.

30. If you have obtained this bid document from our home page or from a source other than directly from the City of Newport News or from www.demandstar.com , you are not on record as a plan holder. The Purchasing Department takes no responsibility to provide addenda to parties not listed by the City as plan holders. It is the bidder's responsibility to check with our office prior to submitting your bid to ensure you have a complete, up-to-date package.

32. The original copy maintained by the Purchasing Department, in the bid file folder, shall be considered the official copy. In the case of any inconsistency between bid/proposal documents submitted to the City, but not clearly listed on the exception page of the document as an exception by the bidder/offeror, the language of the official copy shall prevail. Furthermore, any exception or changes to the specifications made by the bidder/offeror may be cause to disqualify your bid/proposal.

33. The City has a directory of Newport News Minority and Women-owned businesses. The directory is distributed, at request, at no additional cost.

> "It is the policy of the City of Newport News to facilitate the establishment, preservation, and strengthening of small businesses and businesses owned by women and minorities and to encourage their participation in the City's procurement activities. Toward that end, the City of Newport News encourages these firms to compete and encourages non-minority firms to provide for the participation of small businesses and businesses owned by women and minorities through partnerships, joint ventures, subcontracts, and other contractual opportunities. Bidder is requested to include a statement indicating the planned use of such businesses in fulfilling this contract."

34. This public body does not discriminate against faith based organizations.

GENERAL

This Invitation for Bid shall be the basis for establishing a Blanket Purchase Order Contract to cover stock requirements for 5/8", 5/8" x ¾", ¾", 1", 1-½" and 2" cold water meters. The contract period will be for a twelve month period, commencing on the Date of Award. A renewal option as specified below may be exercised. Only those items specified herein may be furnished. The City reserves the right to negotiate additional sizes of meters to be added to the contract during the original contract term and/or subsequent renewal periods. Any substitution of material will require prior approval by the City of Newport News.

Bids from manufacturer distributors will *not* be considered.

SUBMITTALS

Each manufacturer submitting a bid should also submit the following affidavits:

- That the manufacturer has been actively engaged in the manufacture and marketing of each make, model and size of meter offered, or a substantially similar type of meter, for a period of at least ten (10) years.

- That each make, model and size of water meter offered is manufactured under an ISO 9001 certified quality system.

- That each make, model and size of water meter offered complies with all applicable standards as specified in the American Waterworks Association (AWWA) Standard C700-02 (latest revision) Cold-Water Meters—Displacement Type, Bronze Main Case.

- That, at minimum, each make, model and size of water meter offered complies with the National Science Foundation (NSF) Standard 61, Drinking Water Systems Components-Health Effects.

Each bidder must submit a statement of warranty for water meter accuracy, main cases, registers and measuring chambers for each make, model and size of meter offered.

QUANTITY

The estimated quantities of meters for this bid are based on an annual projected requirement. It is explicitly stated as an estimate *only* and shall not obligate the City of Newport News to purchase any specified number of water meters. It is also further understood that the City shall not be obligated to purchase or pay for any water meters unless and until ordered and received by the City.

RENEWAL OPTION

At the discretion of the City of Newport News the contract may be renewed for up to four additional years in one-year increments.

FIRM PRICING

Quoted pricing shall remain firm for the entire contract term, to include periods of renewal. The City of Newport News reserves the right to negotiate reductions in the quoted price schedule at any time during any contract term.

CANCELLATION

The City of Newport News may cancel the contract with the manufacturer at any time for poor-performance by the manufacturer. Cancellation shall not release the manufacturer from legal remedies available to the City.

At the end of the first contract term or each renewal period thereafter, either party may terminate the contract in part or whole without penalty. Written notice of such termination must be made a minimum of sixty (60) calendar days prior to the end of any contract period.

DELIVERY

Receipt of a Blanket Purchase Order does not constitute an authorization to ship. A delivery authorization shall be phoned in or signed by a designated representative of the City of Newport News. Each shipping release will be a separate authorization under the terms of this Purchase Order for the manufacturer to ship the quantities and sizes of meters referenced on the shipping release. The authorized release form, where applicable, shall be titled “Purchase Order Release.” The release shall contain the following information:

- Purchase Order Number
- Release Number (issued sequentially)
- Date of Issue
- Item Number to Match the Itemized Blanket Order
- Release Quantity
- Description of Items

Delivery time is important to the City of Newport News and may be a consideration in the award of this bid. The City considers delivery time to be that period elapsing from the time the individual order is placed until the City at the specified delivery location receives the order. The bidder shall indicate (in the space provided) delivery time in calendar days after receipt of order to release:

Deliveries shall be made to The City of Newport News Waterworks, 425 Industrial Park Drive, Newport News, VA 23608. Deliveries will be accepted between the hours of 8:00 a.m. and 2:30 p.m., Monday through Friday. Delivery of individual items in other than standard bulk packaging may be required.

METER SHIPMENT AND IDENTIFICATION

Each shipment of meters shall be clearly marked with a Purchase Order Number and with the applicable shipping release number(s). Each shipment of meters shall also include a listing of meter serial numbers and a certificate of accuracy testing for each meter in the shipment. Each shipment of meters must also be accompanied with a Compact Disk (CD) / electronic file in Excel format listing every meter number serial number and all pertinent testing information. **Bidders should include in their bid a copy of the information contained in their CD.** At a minimum, the manufacturer, year of manufacture, unit of measure, make, model, size and gear identification shall be on the electronic file.

INVOICING

Billing to the City shall be presented monthly on invoice forms in duplicate and must reference the Purchase Order Number and Release Number, which will be given to the Contractor by a designated representative of the using agency/department, for each transaction.

Invoices shall be submitted to Accounts Payable, Finance Department, City of Newport News, 2400 Washington Avenue, Newport News, VA 23607.

SILENCE OF SPECIFICATIONS

The apparent silence of these specifications and any supplemental specifications as to any detail or the omission from the specifications of a detailed description concerning any point shall be regarded as meaning that only the best commercial practices are to prevail and that only materials of the highest quality and correct type, size and design are to be used. All interpretations of these specifications shall be made on the basis of this statement.

GENERAL DESCRIPTION

5/8”, 5/8” x ¾”, ¾”, 1”, 1 ½”, and 2” POSITIVE DISPLACEMENT COLD WATER METERS

GENERAL REQUIREMENTS

Except as otherwise modified, supplemented or stipulated herein, the American Waterworks Association (AWWA) Standard C700-02 (or latest revision) Cold-Water Meters—Displacement Type, Bronze Main Case shall govern the material, design, manufacture, and testing of all water meters furnished under this specification. All meter identification, register and housing, shall be clearly legible for the duration of the warranty.

SPECIFIC REQUIREMENTS

Registers

The meter register shall be constructed of a corrosion resistant material. It shall be magnetically driven and permanently roll sealed against disassembly of the gear train. The meter register shall be of the straight reading type and indicate in cubic feet. All digits shall be black numerals on a white background except the right two digits. The right two digits shall be white numerals on a black background (number wheel or fixed). The register shall have a “low flow” or “leak indicator”. The manufacturer, year of manufacture, unit of measure, make, model, size and gear identification shall be printed on the register face.

Register Boxes and Lids

The register box and lid for the 5/8”, 5/8” x ¾”, ¾”, and 1” meters shall be made of a suitable engineering plastic.

The register box and lid for the 1-½” and 2” meters shall be made of bronze.

All register lids shall have imprinted on them the meter manufacturer and meter serial number.

The register box shall be secured to the main case by an internal or external tamper-proof locking device. Lead seals and wire will not be accepted.

Main Cases

As a minimum, all meter main cases shall be made of a lead free brass containing no less than 75 percent copper that meets ANSI/NSF Standard 61. It shall have a separate measuring chamber that can be easily removed from the case. The meter serial number shall be stamped between the outlet port of the main case and the register. Main case markings shall be cast raised or be cast raised within 6 months after award and shall indicate size, model, direction of flow and NSF Standard 61 certification.

Main cases for 5/8”, 5/8” x ¾”, ¾” and 1” meters shall be of the frost protection design with a cast iron bottom cap. The internal portion of the bottom cap shall be protected from corrosion by an inner lining or coating. The meter main case connections shall be meter-casing spuds having external straight threads.

Main cases for 1-1/2” and 2” meters shall be of the split case design with lower and upper shell assemblies. The meter main case connections shall be flanged on both ends.

All main case bolts, nuts and washers shall be of a non-magnetic corrosion resistant material. No exposed threads on bolts.

Measuring Chambers

The measuring chamber shall incorporate a nutating disc design. The chamber and components shall be made of a suitable engineering plastic.

5. Strainers

All meters shall be provided with an internal strainer.

ACCURACY OF REGISTRATION AND CAPACITY

All meters offered shall be tested by the manufacturer for capacity and accuracy of registration at flow rates and test flow quantities in accordance with AWWA Standard C-700-02 Section 4.2 and AWWA Manual M6, Chapter 5, Table 5-3. The manufacturer shall also provide a certificate documenting that each meter has been tested and that it complies with the stated capacity and accuracy of registration requirements.

The City of Newport News Waterworks will test a statistically controlled sample of each new meter shipment. The successful bidder shall credit the City a $15.00 retest fee for each new meter that fails to meet new meter accuracy standards.

The City shall not accept any defective meter or meters, which stop up, have missing, broken or loose components, components which have become disconnected from their intended connections, shipping damages, and/or improper operation or registration.

WARRANTY ADMINISTRATION

During all manufacturer stated guarantee periods for issues relating to meter accuracy and manufacturing defects in workmanship and material, the City will notify the manufacturer for repair or replacement at no cost to the City, to include labor, materials and shipping. Upon notification by the City of a warranty return, the manufacturer shall initiate the pickup and delivery of the meter(s) to the proper repair facility at no cost to the City.

If the manufacturer rejects meters for repair or replacement under warranty the manufacturer shall provide the City, on company letterhead, a listing of each meter rejected and a detailed justification for its rejection.

Meters returned under warranty by the City will be accompanied by a packing list referencing all meters returned and the reason for their return. The manufacturer shall be responsible for all costs associated with returned meters.

PARTS

All meters shall be constructed, such that they may be repaired in purchaser's meter shop and all parts and special tools necessary for such repairs shall be made available from vendor.

Bidder should provide the City with complete specifications, literature, and manufacturer's current price list(s) for repair parts for each size water meter bid.

Bidder shall provide the City with a percentage discount off of the repair parts list(s).

MAINTENANCE PLAN

As a part of the bid package, the manufacturer is to submit information on maintenance plans that are available for each size meter identified in this bid. This information is to identify any incentive programs that are available for the rebuilding, replacement or exchange of the water meters. The maintenance plans are offered as options that are not associated with the product warranty.

USED/SCRAP METERS

The City of Newport News is interested in establishing one or more contracts for the *sale* of used/scrap meters for cash (no credits permitted). Once identified as used/scrap meters, the successful company shall be responsible to initiate and coordinate the pickup and delivery of all used/scrap meters to the proper delivery destination at no cost to the City.

The contract period for the sale of used/scrap meters shall be extended ninety (90) days beyond the contract term established for new meter purchases.

The City shall not be bound in anyway to specific quantities of used/scrap meters, nor shall any specified quantities of used/scrap meters restrict the sale of such meters. The purchase of new meters and the sale of used/scrap meters are independent activities. While a multiple award may be made, for administrative efficiency the City may elect to bundle the purchase/sale activities into one contract.

Bidders may not be restrictive and must be willing to accept any and all of the manufacturers and models listed below, for a particular size at their offered purchase price.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scrap/Surplus Meters

Neptune Meter

Size 5/8”, 5/8” x ¾”, ¾”, 1”, 1.5” and 2” Model T-10

Badger Meter

Size 5/8” Model 25 Recordall

Size 5/8” x ¾” Model 25 Recordall

Size ¾” Model 35 Recordall

Size 1” Model 70 Recordall

Size 1.5” Model 120 Recordall

Size 2” Model 170 Recordall

AMCO (ABB) Meter

Size 5/8” Model C700

Size 5/8” x ¾” Model C700

Size ¾” Model C700

Size 1” Model C700

Size 1.5” Model C700

Size 2” Model C700

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Quotation Form
Company Name:

Depending upon requirements of the application, The City of Newport News may purchase Safe Drinking Water Act (SDWA) "Lead Free" (lead content less than 8%) and/or Envirobrass® II Water Meters "No-Lead" (lead content 0.25% or less), that meet or exceed the ANSI/NSF 61 standard. The City reserves the right to be the sole determiner on which meters are in the best interest of the City.

Section 1: New Water Meters Meeting the SDWA "Lead Free" Designation (Lead Content < 8%)

Item #	Estimated Annual Quantity	Size	Model	Unit Price	Extended Price
1	10,000	5/8"		$	$
2	100	5/8 X ¾"		$	$
3	500	¾"		$	$
4	750	1"		$	$
5	750	1.5"		$	$
6	750	2"		$	$
Specify Manufacturer's Name for Items Bid Above:				**TOTAL**	$

Section 2: New Water Meters, Envirobrass® II "No Lead" (Lead Content 0.25% or Less)

Item #	Estimated Annual Quantity	Size	Model	Unit Price	Extended Price
7	10,000	5/8"		$	$
8	100	5/8 X ¾"		$	$
9	500	¾"		$	$
10	750	1"		$	$
11	750	1.5"		$	$
12	750	2"		$	$
Specify Manufacturer's Name for Items Bid Above:				**TOTAL**	$

Section 3: Used/Scrap Water Meters for Sale by the City

Item #	Estimated Annual Quantity	Size	Model	Unit Price	Extended Price
13	10,000	5/8"		$	$
14	100	5/8 X ¾"		$	$
15	500	¾"		$	$
16	750	1"		$	$
17	750	1.5"		$	$
18	750	2"		$	$
				TOTAL	$

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Company Name:
____

In addition to the Pricing Quoted Above, Bidder is to also submit/respond to the following:

1. Delivery Time: Specify the number of calendar days required from the time that an individual order is placed until the order is delivered to the specified delivery location:

   ___________ calendar days

2. By submitting a bid and initialing each paragraph below, bidder certifies that:

   - The manufacturer has been actively engaged in the manufacture and marketing of each make, model and size of meter offered, or a substantially similar type of meter, for a period of at least ten (10) years.

     ____

   - Each make, model and size of water meter offered is manufactured under an ISO 9001 certified quality system.

     ____

   - Each make, model and size of water meter offered complies with all applicable standards as specified in the American Waterworks Association (AWWA) Standard C700-02 (latest revision) Cold-Water Meters—Displacement Type, Bronze Main Case.

     ____

   - At minimum, each make, model and size of water meter offered complies with the National Science Foundation (NSF) Standard 61, Drinking Water Systems Components-Health Effects.

     ____

3. Each bidder must submit a statement of **warranty** for water meter accuracy, main cases, registers and measuring chambers for each make, model and size of meter offered.

4. As a part of the bid package, the manufacturer is to submit information on **maintenance plans** that are available for each size meter identified in this bid. This information is to identify any incentive programs that are available for the rebuilding, replacement or exchange of the water meters. The maintenance plans are offered as options that are not associated with the product warranty.

Company Name:

____

5. Bidder should provide the City with complete specifications, literature, and manufacturer's current price list(s) for **repair parts** for each size water meter bid.

   Bidder shall provide the City with a percentage discount off of the repair parts list(s).

   Repair Parts Discount for all meters:

   __________% off of price list in effect at time of parts purchase.

6. Each **shipment of meters shall be clearly marked** with a Purchase Order Number and with the applicable shipping release number(s). Each shipment of meters shall also include a listing of meter serial numbers and a certificate of accuracy testing for each meter in the shipment. Each shipment of meters must also be accompanied with a Compact Disk (CD) / electronic file in Excel format listing every meter number serial number and all pertinent testing information. <u>Bidders should include in their bid a copy of the information contained in their CD</u>**.** At a minimum, the manufacturer, year of manufacture, unit of measure, make, model, size and gear identification shall be on the electronic file.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

IFB (2005-46457-0224)

Since it is the intent of the City to promote small businesses (SBE), minority businesses (MBE), and women-owned businesses (WBE), you are **requested** to report the total dollars which will be **sub-contracted** to each of the business classifications pertaining to this contract. If you should sub-contract with SBE's, MBE's and WBE's, list the dollar figures separately for each general classification.

This will enable the City to track the amount of business the City does with small, minority and women-owned businesses. Without your cooperation it would be very difficult to fully understand the City' performance in this important segment of the market. Indicate your figures below and return this form to the Purchasing Department **with your initial bid package.**

If you are not subcontracting, even if you are a S/M/WBE, put zeros in the spaces below.

SBE Dollars to be Sub-contracted
$__________

MBE Dollars to be Sub-contracted
$__________

WBE Dollars to be Sub-contracted
$__________

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

ANTI-COLLUSION CERTIFICATION

The bidder certifies that this bid is made without prior understanding, agreement, or connection with any corporation, firm, or person submitting a bid for the same product and that this bid is in all respects bona fide, fair and not the result of any act of fraud or collusion with another person or firm engaged in the same line of business or commerce. The bidder understands collusive bidding is a violation of Federal Law and that any false statement hereunder constitutes a felony and can result in fines, imprisonment, as well as civil damages. The bidder also understands that failure to sign this statement will make the bid non-responsive and unqualified for award.

Signed: ________________________________
Date:__________________________________

Name of Company:
____

Notary: _________________________________ My term expires:
____

Date: ___________________________________
Seal:__________________________________

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

<u>EXCEPTIONS</u>:

Note: Bidder must sign the appropriate statement below, as applicable:

( ) Bidder understands and agrees to all terms, conditions, requirements, and specifications stated herein.
Firm: ____

Signature: ____

( ) Bidder takes exception to terms, conditions, requirements, or specifications stated herein (Bidder must itemize all exceptions below, and return <u>with</u> this IFB submittal):

Firm: ____

Signature: ____

____

____

Specify payment terms if other than "2%-20, Net 30": ____________________

Payment terms shall be considered in determining the low bidder.

Vendors should note that any exceptions taken from the stated terms and or specifications may be cause for their submittal to be deemed "Non-responsive", risking the rejection of their submittal.

BID RESULTS

Bid results of the apparent three low bidders will be made available on recorded message the following two business days after the bid opening, by calling (757) 926-7261. Results may also be obtained from our website at:
www.newport-news.va.us/purchase/index.htm or www.demandstar.com

For a tally sheet, please send a <u>stamped, self-addressed envelope</u>, indicating the bid number, date opened, and a note requesting the tally information. There is a handling charge of $.25 per sheet to reproduce the information. You may contact the Purchasing Department to determine the number of sheets. This information is also available on: www.demandstar.com

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Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Philadelphia Water Department
Philadelphia, PA
AwwaRF Project 3018 Case Study

Utility Profile

Source water	Delaware River – 50% Schuylkill River – 50%
Surface Treatment	Three conventional treatment plants with similar processes: sedimentation, coagulation, flocculation, and clarification, followed by rapid sand or dual-media filtration.
Groundwater Treatment	None
Corrosion control treatment	Zinc orthophosphate addition/ Finished water pH of 7.2 at each of the three plants.
Daily demand	Average daily demand: 250 MGD
Total customer population base	1,500,000
Service line ownership	Customer-owned from main to in-house plumbing. PWD owns meters, typically located in homes.
Lead service line	Service lines are primarily copper. PWD typically replaces any remaining lead service lines from main to curbstop when re-connecting services to replaced main.
Type of replacement program	Lead service line replacement program Meter replacement program

LCR BACKGROUND

The finished water produced by Philadelphia Water Department's (PWD) treatment plants has consistently had lead levels of less than 0.001 mg/L and copper levels of 0.08 mg/L. Since 1992, when the LCR came into effect, PWD has conducted eight rounds of customer tap sampling for compliance with the LCR. Results of the tap sampling efforts are presented in Table B.7.1. As Table B.7.1 shows, PWD exceeded the lead action level once, during the first round of sampling, and has never exceeded the copper action level. PWD became optimized for corrosion control in 1997. PWD has implemented corrosion treatment in the form of zinc orthophosphate addition. Optimized corrosion control conditions in the distribution system include maintaining pH above 7.1 and a zinc orthophosphate level of greater than 0.60 mg/ L as phosphorous.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table B.7.1
PWD Historic LCR Monitoring Results

	Monitoring Period							
	2005	2002	1999	1998	1997 Jul-Dec	1997 Jan-Jun	1992 Jul-Dec	1992 Jan-Jun
Lead*								
90th %	0.009	0.013	0.009	0.010	0.011	0.014	0.015	0.021
Copper*								
90th %	0.3	0.3	0.3	0.3	0.4	0.4	0.8	0.9

*All results are expressed in mg/L

LEAD SERVICE LINE REPLACEMENT PROGRAM

As indicated earlier, PWD customers own the service lines from the connection to the main to the in-house plumbing. Due to this situation, PWD does not have the authority to repair, replace, or maintain the service line. Therefore PWD does not have a formal lead service line replacement program.

However, when PWD is conducting replacement of water mains, all service lines are replaced from the new main to the existing curbstop, regardless of the material that was present. Homeowners are responsible for replacing the remaining portion of the service line. PWD contacts each homeowner in advance to provide them with the opportunity to replace the remainder of the line while PWD is working on the site. In addition, PWD has a loan program to assist homeowners in replacing defective lines (although lead service lines in themselves are not classified as a defect). PWD is working to increase the amount of time between notifying the homeowner and the service line partial replacement as well as putting together cost information comparing costs of service line replacement done while PWD is working on the site versus at a later date. It is anticipated that these efforts will encourage homeowners to replace their lead service lines.

OTHER ISSUES

As part of ensuring continued compliance with the LCR, PWD has conducted reviews of their LCR compliance monitoring results as well as more specific monitoring to evaluate the potential contribution that faucets may have on lead levels measured at the tap. These issues are discussed below.

Review of LCR Tap Sampling Results –Sites With and Without Lead Service Lines

PWD has performed evaluations of lead and copper tap samples collected for LCR compliance, to consider the correlation of lead service lines with lead tap levels. Table B.7.2 presents a comparison of customer tap sampling results for homes with lead service lines and lead solder and homes without lead service lines but with lead solder in the plumbing systems. As these data demonstrate, in all but one tap sampling round (1999), the 90th percentile of lead sampling results for homes without lead service lines is higher than the 90th percentile for homes

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

with lead service lines. These results may suggest that the characteristics of the customer plumbing after the service line and meter, such as the presence and condition of lead solder and the presence of lead containing materials such as brass valves or faucets, could be important in determining exposure to lead in drinking water.

Table B.7.2
Lead Tap Sampling Results – Homes with and without lead service lines

Sampling Period	90th Percentile – Homes with Lead Service Lines, Lead Solder (mg/L)	Number of Samples Collected	90th Percentile – Homes without Lead Service Lines, but with Lead Solder (mg/L)	Number of Samples Collected
Jan – Jun, 1992	0.016	81	0.031	81
Jul – Dec, 1992	0.012	72	0.019	71
Jan – Jun, 1997	0.008	58	0.017	60
Jul – Dec, 1997	0.009	53	0.011	55
Jun – Sep, 1998	0.005	42	0.011	36
Jun – Sep, 1999	0.014	30	0.009	29

Potential Impacts from Faucets

In order to gain a better understanding of the impacts of sample collection and brass-containing faucets on sampling results, PWD has conducted special studies in-house. In one study, three typical faucets with a common shared hot and cold spout were evaluated to determine typical faucet volumes. It was found that the average spout could contained 60 ml of water (Burlingame, 2003). When including the tubing, the average volume of water in contact with brass materials for the three faucets was 117 ml (Burlingame, 2003).

Additionally, PWD compared lead samples of different volumes taken from the same faucet to look at the impacts of both the sample collection and the faucet on lead levels (Burlingame, 2003). Six first-flush samples were collected on six consecutive days. Sample volumes, alternated in volume between 1000 ml and 50 ml (i.e. 1000 ml sample collected Monday and a 50 ml sample collected Tuesday). The faucet had been flushed with hot water the previous night and hot water was left standing for 7.0 – 7.5 hours. Then, a first-flush sample was collected using cold water. On average, the 1000 ml lead samples contained 0.060 mg/L of lead and the 50 ml samples contained 0.365 mg/L lead. These findings indicate that this particular faucet contributed a significant amount of lead to the tap sample. Additionally, PWD indicates that if a faucet held 50 ml of water containing 0.365 mg/L lead after standing over night, then the first flush liter sample could be raised significantly. For example, assuming a background level of 0.005 mg/L lead in the water, the collected tap sample could contain a lead level of 0.023 mg/L (Burlingame, 2003).

In another study conducted at the same home, samples of varying sizes were collected after hot or cold water stood overnight in the piping. The 17 samples collected varied in size from 50 to 1000 ml and the first-flush sample was collected using cold water. For 1000 ml samples, the average lead level was 0.060 mg/L for the hot standing water samples, while the average lead level for cold standing water samples was 0.027 mg/L. For both the hot and cold standing water samples, smaller sample volumes resulted in higher lead levels. Hot standing water samples with a volume of 50 ml had average lead levels of 0.365 mg/L, more than five times higher than the larger, hot water sample. The 125 ml, cold standing water samples had average lead levels of 0.042 mg/L.

In 2001, PWD conducted non-regulatory monitoring to investigate lead contributions by faucets for the AwwaRF project entitled *Post Optimization Lead and Copper Control Monitoring Strategies* (AwwaRF 2005). This monitoring took place at 25 homes that were at least 20 years old over 10 weeks and included both lead and copper analysis. The study involved collecting 10 rounds of samples, with a split sample, composed of a 125 ml followed by 1000 ml sample, taken during the 1st and 10th sampling rounds. During the rest of the sampling, 1000 ml samples were collected. Samples were collected after a stagnation period, typically ranging from five-and-one-half to nine-and-one-half hours. The average lead level in the 1000 ml samples was 0.0022 mg/L, with a 90th percentile level of 0.003 mg/L. The split sample averages were 0.0035 mg/L (125 ml sample) and 0.0043 mg/L (1000 ml sample). For these samples, the 90th percentiles were 0.0050 mg/L for both sample sizes. Further analysis indicated that there were essentially no statistical differences in lead levels in tap samples based on sample volume or size and age of piping. Additionally, these results exhibited lower variability and lower lead levels than those collected for LCR compliance (AwwaRF 2001).

In 2006, a study of the release of metals from kitchen faucets was completed (PWD 2006). In this study, new faucets were purchased and installed in both a test system at the PWD laboratory and in actual home installations. Four faucets were installed in the laboratory test facility and 3 faucets were installed in homes. All of the faucets selected were NSF/ANSI Standard 61 Section 9 certified and the faucets used for home installation were the same models as faucets installed in the laboratory testing system. The volume of water in contact with the brass and non-brass internal features of each faucet was calculated. Table B.7.3 lists the contact volumes for each type of faucet. First draw stagnation samples were drawn (minimum 6 hour stagnation) from both the laboratory and the field installed faucets. Use of the field installed faucets was unrestricted and the laboratory faucets were flushed at full volume for a total of 20 minutes, four times a day during the week, and for 40 minutes once a day on the weekends. Metals levels were measured from water samples collected after an overnight standing period, in consecutive 250 mL increments. Table B.7.4 lists the lead level results for each faucet.

Table B.7.3

Faucet Contact Volumes

Faucet	**Contact Volume, mL**		
	Brass	Copper	Total
1	85	0	85
2	50	20	70
3	50	15	65
4	110	0	110

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Results indicated that the highest lead levels occurred in the first 250 mL of water collected after stagnation, in the first week of operation, but occasional high lead levels occurred weeks later. Lead release ceased after the fourth week for all but one lab faucet and after the third week for all but one field faucet. Copper release continued throught the 28 week study for both groups of faucets. Larger contact volumes of the faucets did not generally correspond to higher levels of lead or copper release.

Table B.7.4
Maximum Lead and Copper Levels in First 1000 mL sample

Time in Use, weeks	Maximum Lead in the First 1000 mL of Water						
	A-Lab	B-Lab	C-Lab	D-Lab	A-Field #1	A-Field #2	D-Field
1	0.012	0.006	0.004	0.003	0.005	0.006	0.007
2	0.004	0.009	0.007	0.002	0.002	-	0.002
3	0.002	0.003	0.009	0.002	0.002	0.002	0.002
4	0.003	0.003	0.010	0.002	0.002	0.004	0.002
5	0.002	0.005	0.002	0.002	0.002	0.002	0.002
6	0.002	0.003	0.002	0.002	0.002	0.002	0.002
7	0.002	0.005	0.002	0.002	0.002	0.002	0.002
15	0.002	0.004	0.004	0.002	0.004	0.003	0.002
28	0.003	0.005	0.002	0.001	0.001	0.002	0.001
	Maximum Copper in First 1000 mL of Water						
	A-Lab	B-Lab	C-Lab	D-Lab	A-Field #1	A-Field #2	D-Field
1	0.087	0.058	0.036	0.026	0.141	0.216	0.176
2	0.023	0.17	0.126	0.039	0.188	-	0.148
3	0.024	0.058	0.169	0.027	0.134	0.223	0.134
4	0.022	0.073	0.210	0.041	0.177	0.227	0.128
5	0.015	0.133	0.037	0.103	0.134	0.243	0.150
6	0.016	0.059	0.027	0.025	0.144	0.224	0.150
7	0.014	0.124	0.029	0.026	0.143	0.243	0.126
15	0.012	0.079	0.138	0.022	0.014	0.255	0.111
28	0.136	0.075	0.042	0.022	0.165	0.322	0.124

SUMMARY

PWD's situation with respect to lead service lines is unique in that the entire line is owned by the customer. While replacing mains, PWD replaces lead lines with copper from main to the curbstop and encourages the homeowner to take care of the remaining portion at the same time. PWD has also conducted investigations of faucets as potential lead sources and tap sampling methods. Finally, PWD has analyzed LCR compliance data to evaluate the relationship between lead service lines and sample results.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

REFERENCES

Burlingame, Gary. 2003. Philadelphia's Lead and Copper Data: Usefulness for Tracking Changes in Corrosion Control under the Lead and Copper Rule. Philadelphia Water Department Internal document (?).

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PWD. 2006. "Leaching of Metals from Kitchen Faucets." Prepared by Scientific and Regulatory Affairs (SRA) Bureau of Laboratory Services, Philadelphia Water Department (PWD). June 20, 2006.

Portland Water Bureau
Portland, OR
AwwaRF Project 3018 Case Study

Utility Profile

Source water	Bull Run Watershed surface impoundments and Columbia River South Shore groundwater wells.
Surface treatment	Chlorine disinfection, pH adjustment, secondary disinfection with chloramines.
Groundwater treatment	Chlorine disinfection, pH adjustment, secondary disinfection with chloramines.
Corrosion control treatment	pH adjustment with sodium hydroxide
Daily demand	Average daily demand: 106 MGD
Total customer population base	770,000
Lead service lines	None
Type of replacement program	Lead gooseneck removal and replacement with copper

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BACKGROUND

The Portland Water Bureau (PWB) provides potable water primarily from an unfiltered surface water supply originating in the Bull Run watershed located approximately thirty-five miles east of Portland. Water is disinfected at the headworks facility with chlorine. Ammonia (as NH_4OH) and sodium hydroxide (as NaOH) is added at the Lusted Hill Treatment Facility approximately 10 miles downstream. PWB also operates a supplemental groundwater supply located along the Columbia River during high demand periods and emergencies. When in use, groundwater is disinfected with chlorine followed by ammonia addition and pH adjustment prior to entering the distribution system. The target pH for the groundwater supply is 8.0. The treated Bull Run supply is typically within a pH range of 7.5-8.0 and an alkalinity of 6-12 mg/L as CaCO3.

PWB is in compliance with all requirements set forth by the State of Oregon Department of Health Services (DHS) Drinking Water Program. Since 1997, the PWB has exceeded the lead action level 6 times in 17 rounds of monitoring (GAO-04-974T, July 22, 2004; www.gao.gov/new.items/d0497t.pdf). Currently, and per agreement with DHS, the Portland Water Bureau conducts a Lead Hazard Reduction Program as an alternative to providing optimal corrosion control.

LEAD SOURCE REPLACEMENT PROGRAM

Prior to PWB's development and implementation of the Lead Hazard Reduction Program, the utility undertook a program to remove lead sources from elements of the

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

distribution system under PWB ownership. PWB's program for removing lead gooseneck was part of a compliance agreement reached with the Oregon State Health Division following the state's 1984 ban on the use of lead in plumbing. Specifically, the program objective was to remove lead goosenecks from customer service connections and replace them with copper pipe. A lead gooseneck is a 1.5 to 2 foot section of lead pipe about ¾ inch in diameter that connects the service line to the water main. Because the gooseneck is malleable and flexible, it is helpful in installing a service. Lead goosenecks were installed during the 1920s and 1930s.

In 1982, the PWB sponsored a study that demonstrated the contribution of lead goosenecks to lead levels in drinking water (JMM 1983, Consulting Engineers, Inc, October, 1983 "Internal Corrosion Mitigation Study Addendum Report"). The study involved taking multiple consecutive samples from faucets until reaching the water from the main. High lead levels were found in the samples that corresponded with the samples volumes that were in the gooseneck. The study did not sample homes after the goosenecks were replaced, but since all services that had a lead gooseneck were replaced with copper from the main to the meter, one could assume that all the lead from the goosenecks was removed.

Prior to 1982, PWB's practice was to remove and replace goosenecks when located through normal maintenance. PWB began actively removing lead goosenecks in fiscal year 1982-83 with the removal and replacement of 1,032 connections. The program continued annually and was completed in April 1998. During the program's sixteen year period, PWB crews removed and replaced 12,562 lead goosenecks at an average rate of 785 per year (Figure B.8.1). Between 1984 and 1997 the cost of repair and replacement was approximately $10 million dollars or $796 each. This figure does not include the 2,518 goosenecks (20% of total) removed between 1982 and 1984. The actual cost of the total gooseneck removal program may be closer to $12 million dollars.

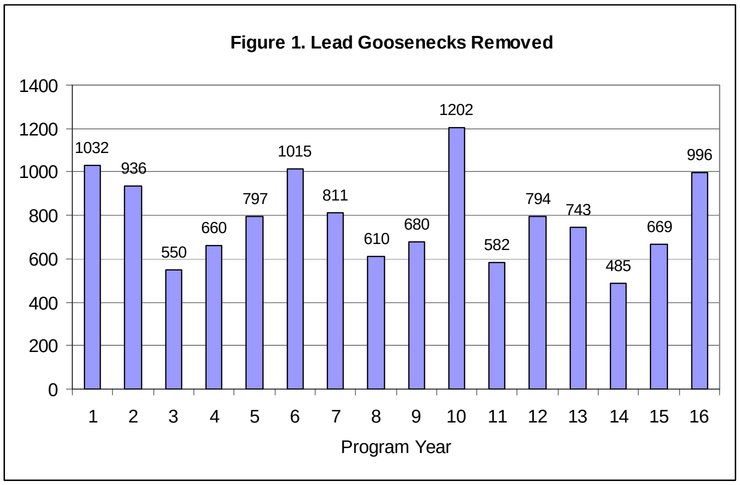

Figure B.8.1 Lead Gooseneck Removal Program

Most of the locations connected with lead goosenecks were outside the USEPA definition of Tier 1 homes (defined as homes constructed after 1984). Because of the age of the homes characterized by lead goosenecks, few, if any, were monitored under the required Lead and Copper Rule (LCR) compliance monitoring after 1991. Because there was no regulatory requirement addressing the removal and replacement prior to 1991, and that locations were not monitored Tier 1 homes after 1991, and the full leaded section was removed, water quality

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

monitoring was not conducted with regards to pre- and post-removal lead levels. Therefore, a quantified benefit in terms of reduced lead levels is not available.

Following the gooseneck removal program PWB implemented a unique Lead Hazard Reduction Program that includes:

- Water treatment (pH adjustment) and water quality monitoring
- Home lead hazard reduction
- Stakeholder involvement, public education and community outreach
- Lead-in-Water Testing Program

SUMMARY

The Portland Water Bureau proactively addressed lead goosenecks on utility-side owned plumbing as early as 1982. During a sixteen year program PWB removed and replaced 12,562 lead gooseneck at a cost of approximately $12 million dollars. The program removed approximately 19,000 – 25,000 linear feet of lead from the distribution system. Because the goosenecks were typically associated with homes constructed during the early half of the 1900's, the goosenecks were located in residences that were outside the USEPA definition of Tier 1 homes for LCR compliance monitoring. Locating, removing, and replacing the connections removed lead from the distribution system that would not have been otherwise monitored under LCR requirements.

REFERENCES

Montgomery, James M Consulting Engineers Inc. (JMM). 1983. *Internal Corrosion Mitigation Study Addendum Report*. Portland Water Bureau. Portland, OR.

San Francisco Public Utilities Commission
San Francisco, CA
AwwaRF Project 3018 Case Study

Utility Profile

Source water	Hetch Hetchy Reservoir (85%) Local Alameda and Peninsula watersheds (15%)
Surface treatment	Hetch Hetchy water is an approved unfiltered water supply. Primary disinfectant is sodium hypochlorite; and residual disinfectant is chloramines. Local Alameda reservoir supply is treated at Sunol Valley WTP, a conventional treatment plant with free chlorine as primary disinfectant and chloramines as residual disinfectant. Local Peninsula reservoir supply is treated at the Harry Tracy WTP, a direct filtration treatment plant with ozone as primary disinfectant and chloramines as residual disinfectant.
Corrosion control treatment	pH adjustment of Hetch Hetchy water using lime at location upstream of primary disinfectant injection point.
Daily demand	Average daily demand: 260 MGD
Total customer population base	2.4 million people including those supplied via 28 retail agencies.
Service line ownership	Customer owns from meter.
Lead service line	Replaced all known lead service lines (10,000+) between 1983 and 1988. If lead service lines are found in the system today, they are replaced as a standard procedure.
Type of replacement program	Discontinued installation of lead joints; lead service line replacement; faucet distribution program; meter replacement.

BACKGROUND

The San Francisco Public Utilities Commission (SFPUC) proactively reduces lead exposure in City drinking water through corrosion control treatment optimization, compliance with the Lead and Copper Rule (LCR), bench and pilot-scale testing programs, and voluntary lead source reduction programs. The SFPUC has completed several lead source reduction measures such as the discontinued installation of lead joints in water mains (1983) and the removal of all known lead service lines (1983-1988). More than 10,000 lead service lines were removed from the system during that time. The SFPUC has several on-going lead source reduction programs including a meter replacement program and a lead-free faucet distribution program.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Corrosion control was implemented as early as the 1930's. In 1950, a new chemical feed facility was constructed to add lime to the Hetch Hetchy supply. The facility has run nearly continuously since it was first put on line. Today, the dose of quick lime is adjusted so that a pH of 9.0 to 9.5 is maintained at the Alameda East Portal of the system. When the SFPUC changed the form of chlorine from gaseous chlorine to sodium hypochlorite solution, an added benefit other than the safety issue was improvements in pH stability. In 2004, the SFPUC built redundant corrosion control facilities as part of the chloramines project. Since the commencement of system wide fluoridation in November 2005 and the operation of the redundant corrosion control facilities, the pH of the system water has been further stabilized.

LCR compliance monitoring results, summarized in Table B.9.1, show that the 90th percentile lead levels were above the lead action level (15 µg/L) in three of four monitoring periods before 1997. Since 1998, 90th percentile lead levels have been less than the action level. Historically, 90th percentile copper levels have consistently been below the action level of 1.3 mg/L.

BENCH-SCALE AND PILOT-SCALE TESTING PROGRAMS

In 2000 and 2002, SFPUC's Water Quality Bureau conducted bench-top lead leaching tests to better understand the sources of lead (consumer's plumbing vs. water system's plumbing) and to assess the merits of switching to unleaded in-line fixtures. The testing program in 2000 focused on the comparison of lead leached from the lead-free and unleaded water meters (5/8-inch, 1-inch and 2-inch) and curb stops (1-inch to 2-inch). For the purpose of this case study, the term "lead-free" means plumbing fittings or fixtures containing up to 8% lead as defined by the Congress in the Safe Drinking Water Act, whereas "unleaded" means no more than 0.25% lead content.

The 2002 program evaluated eight types of meters and curb stops and four branded unleaded faucets. Bench testing results indicate that (i) there are significant differences in the amount of lead leached between lead-free and unleaded meters; (ii) curb stops have similar or higher lead leach rates as meters; and (iii) some unleaded faucets leach more lead than the others.

Table B.9.1
SFPUC Historic LCR Compliance Monitoring Results

Date	Lead 90th % Sample (µg/L)	Copper 90th % Sample (mg/L)	Lead/Copper 90th % Sample < Action Level ?	Number of LCR Samples
Feb. 1992	0.016	0.02	No/Yes	119
June 1992	0.018	0.07	No/Yes	102
Oct. 1992	0.013	0.13	Yes/Yes	101
May 1996	0.022	0.12	No/Yes	53
Dec. 1998	0.007	0.13	Yes/Yes	107
April 1999	0.004	0.08	Yes/Yes	103
Aug. 2000	0.005	0.08	Yes/Yes	53
Aug. 2001	0.007	0.12	Yes/Yes	53
Aug. 2004	0.012	0.09	Yes/Yes	54

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

In early 2003, the SFPUC initiated a pilot-scale program to test unleaded curb stops under field conditions to evaluate operations and maintenance issues. The SFPUC used ¾-inch to 2-inch unleaded curb stops. As part of the pilot program, twenty 1-inch unleaded curb stops were installed in new residential connections in the City. After 1-year of installation, these unleaded curb stops were reported to be functioning well. However, the testing will go on before a decision is made on their serviceability. The cost of these unleaded curb stops is reportedly twice as expensive as the existing curb stops used by the SFPUC.

UNLEADED FAUCET DISTRIBUTION PROGRAM

In 1998, the SFPUC's Water Quality Bureau submitted a California Public Health Goals Report to the Commissioners proposing several strategies for reducing lead exposure from drinking water. One of the proposed strategies was to implement a faucet replacement program.

In 1999, SFPUC commissioners adopted a resolution to implement and fund a pilot faucet replacement program in an amount of $80,000 to reduce lead exposure from drinking water to young children at City preschools and daycare centers. Each preschool or daycare center was contacted and offered a free unleaded faucet. By October 2000, about half of San Francisco's 440 childcare centers had received unleaded faucets. The remaining preschools and daycare centers declined to participate in the program for one or more of the following reasons: they did not own the building; they already had unleaded faucets; they were unable to install the faucets; or other reasons. In December 2000, the SFPUC expressed an interest in continuing the giveaway program to high lead sites, schools, and recreation centers.

Due to the success of the pilot faucet replacement program, SFPUC initiated a faucet distribution program for residential customers in 2001. Customers were given the opportunity to purchase a kitchen faucet for $10, a savings of $110. The program objective was to enhance the general public's awareness of the potential lead leaching problem from residential plumbing fixtures. Unleaded faucets were made available for purchase at up to three street sale events each year. To incorporate the residential customer initiative, the program budget was augmented to $147,000 annually. The material cost of lead-free faucets is $108,000, based on an average of 300 faucets sold in each of three sale events per year (each faucet costs about $120). The labor cost associated with the street sales is approximately $39,000.

As the street sales were subject to many constraints such as the available stock of faucets, event facilities, weather conditions, staff resources, and other factors beyond utility staff control, the SFPUC has ceased the street sale events. Instead, an online purchase program was launched in 2004. To participate in the program, customers just need to complete an on-line application and, if determined eligible, applicants are required to sign an agreement that they will install the unleaded faucets within 6 months of purchase. Based on the agreement, the SFPUC has the right to inspect their property to ensure the faucet replacement is done. The customers pay for and pick up their faucets at the utility's customer service counters.

Since 2001, a total of 3,400 unleaded faucets and drinking bubblers have been distributed. Among these, 505 were given to 47 schools in the City. The SFPUC has been unable to inspect residential customer faucet installations due to limited resources and other reasons. Instead, they have relied on a self-policing approach to determine if customers have complied with the agreement to install the unleaded faucet within 6 months of purchase.

The SFPUC also had initiated a unleaded faucet giveaway program for the Women, Infants & Children (WIC) clients, but received a low response rate. Constraints to the program's

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

success included the problem that the unleaded faucets had to be distributed to the landlords of WIC clients. Additional constraints which prevented installation of the faucets included: a lack of skills to complete the installation themselves; a lack of resources to hire a plumber; or a prohibition in the renter's agreement.

METER REPLACEMENT PROGRAM

In December 2000, The SFPUC adopted a resolution to modify the existing water meter replacement program by 1) discontinuing the purchase of leaded brass water meters whenever a suitable unleaded substitute was available and 2) adding an extra annual cost not to exceed $64,000 to make up the difference in the cost of unleaded water meters. In 2002, the SFPUC implemented an unleaded meter replacement program with a goal of replacing 7,000 to 8,000 leaded meters annually over a 20-year period. As of October 2005, about 13,000 unleaded meters have been installed. The sizes of meters included in the program range from 5/8-inch to 2-inch. Annual material and labor costs involved in the meter replacement program is about $700,000, of which $320,000 was attributed to the cost of the meters. As of today, the SFPUC has removed all large compound meters in the City.

CONCLUSION

Because corrosion control was previously optimized and the LCR monitoring results since 1998 have been in compliance with the lead and copper action levels, the SFPUC has no established quantitative objectives associated with their various lead reduction programs. As other plumbing fixtures within residential properties may affect the amount of lead leaching into the tap water, it is difficult for the SFPUC to ascertain a quantitative impact of their programs on tap lead levels. Considering the variety of lead reduction activities that the SFPUC is currently implementing and the continued LCR compliance, the lead source reduction programs are successful at reducing lead exposure from drinking water and protecting public health.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Seattle Public Schools
Seattle, WA
AwwaRF Project 3018 Case Study

Agency Profile

Daily demand	100 gallons per day per person (2003 data)
Total customer population base	47,000 students plus administrative staff
Type of replacement program	End-point devices (water fountains, taps) and building piping replacement

BACKGROUND

Seattle Public Schools provides educational opportunities to 47,000 students in more than 100 schools and administrative buildings. They purchase water exclusively from Seattle Public Utilities (SPU) for drinking water, other potable uses, and fire protection service. More than 60% of the school district structures are plumbed primarily with galvanized steel piping, which is over 40 years old and is moderately tuberculated." (Boyd et al. 2005)

In 1990, the Seattle Public Schools initiated a lead testing and replacement program for water fountains/bubblers. Phase 1 testing in the summer of 1990 included the testing of drinking water from 85 sites and 1,152 endpoint devices. Phase 1 testing represented a worst case scenario because water at most sites had been standing for several weeks. Phase 2 testing, conducted from September to November 1990, involved collecting and analyzing 2,700 drinking water samples for lead. These samples were collected from 1,400 bubblers representing 80 school district sites. Phase III involved data analysis to identify water fountains with low lead content. In Phase IV, all water fountains that had drinking water samples with lead concentrations >20 ppb were replaced. Phase V, conducted between September and December 1992, involved follow-up sampling and analysis on all the replaced water fountains, and collecting initial samples at new or renovated schools. Phase VI was conducted in January and February 1993, to follow-up on lead levels at these fountains. After a gap of nearly 8 years, the school district resumed lead sampling at school water fountains in the Phase VII testing program from 2001 to 2002.

COMPREHENSIVE TESTING AND REMEDIATION PROGRAM (2004-2005)

In January 2004, parental concerns about water quality led the school district to discontinue use of water fountains at all schools built prior to 1997. Supplies of bottled water were provided at these schools while the school district implemented a comprehensive water quality testing and remediation program to correct water quality problems.

The purpose of the comprehensive testing program was to identify existing endpoint devices (i.e. water fountains, classroom and kitchen faucets) with elevated lead levels. Drinking water samples were drawn and analyzed for every school across the system. Samples were typically 250 mL first draw samples representing water that had been standing overnight in water fountains and the connective piping system. In addition to lead, water samples were analyzed for cadmium, zinc, copper, iron, turbidity, color and coliform bacteria. Extensive testing at more

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

than 2,100 separate endpoint devices showed that drinking water samples from about 20% of water fountains had lead concentrations greater than the EPA guideline of 20 ppb (www.seattleschools.org/area/facilities/WaterQuality).

Initially, the school district was focused on meeting the USEPA guideline of 20 ppb for lead in school drinking water. However, because of the high variability noted in lead sampling results in 2004, the school board decided to establish a more stringent lead action level of 10 ppb to "…assure not only compliance with minimum standards, but to give parents, students and staff confidence that they will have access to water which is safe and aesthetically appealing." (Seattle Public Schools 2004). Seattle Public Schools is currently completing remediation of endpoint components that exceeded the 10 ppb lead action level. Remediation plans developed for each individual school were designed to fix identified problems and to meet the criteria set by the school board's water quality policy. Remediation measures include full or partial pipe replacement, replacement of drinking water fixtures (i.e. water fountains, faucets), replacement of flexible connectors and shut-off valves, installation of point-of-use filters that are NSF certified for lead removal and shutting off non-compliant sources that are not needed. Where brass components were replaced, no-lead (0.03% lead) brass components were utilized. These schools have resumed use of City water and have removed temporary supplies of bottled water. Remediation work is continuing at the remaining schools and by the end of 2007 all but 3 schools had resumed use of city water for drinking.

Granular media-based point-of-use (POU) filters were installed at some new fountains after analysis of water samples showed lead levels higher than the school district's 10 ppb action level. POU filters were investigated because they offer a means of mitigating water quality concerns in some schools for an interim period until more extensive piping improvements could be made." (Boyd et al. 2005) As of July 2005, initial testing of 234 newly installed and tested drinking fountains showed that water from these sources contained lead at concentrations above 10 ppb. Pre-conditioning these sources, i.e. flushing them for 24 hours before installation, substantially eliminated this problem.

POU filter installations and sampling at 9 schools indicated that the filters were highly effective for removing lead, cadmium, iron and turbidity. The principal operating concern was that the filters would plug prematurely with iron particulates in buildings with older galvanized steel piping causing reduced flow rates." (Boyd et al. 2005). However, further research showed the filters did not allow breakthrough of lead, rather the failure mode was reduced flow or stoppage.

Laboratory Testing of New End-Point Devices

In 2005, a laboratory testing program was conducted to determine lead releases into drinking water associated with new water fountain fittings and plumbing components installed in Seattle Public School facilities (HDR/EES 2005). Sampling results had shown that some new drinking water fountains exceeded the 10 ppb goal set by Seattle Public Schools. The laboratory approach consisted of stagnation tests and flow-through tests of bubbler heads, flex connectors with brass ends, and brass elbow connectors. Two common types of low-lead (<0.3% lead) bubbler heads were tested.

Stagnation tests were conducted by filling the bubbler or connector with tap water, allowing the unit to contact tap water for a known period of time, and then collecting the water and analyzing it for lead. In preliminary testing, bubbler heads were tested in quadruplicate for a period up to 238 hours (9.9 days). One stainless steel bubbler head was tested for a period of 146 hours (6.1 days). Three brass elbow connectors were connected in series to form a unit, and the brass connector unit was tested in quadruplicate for a period of 141 hours (5.9 days). Flex connectors with brass ends were held in a U-shape and tested in triplicate for a period of 265 hours (11 days). Tap water samples also were collected and analyzed for background concentrations of lead.

Preliminary flow-through tests were conducted by affixing a bubbler head over a sink and running tap water through Tygon tubing to the bubbler head. Water was run continuously at a flow rate of approximately 0.5 gpm. The flow was stopped and water was allowed contact with the bubbler head for 2 hours before collecting a sample. Samples were collected by capturing the first ~25 mL of flow from the bubbler head and analyzing it for lead. In preliminary studies, one low-lead brass and one stainless steel bubbler head were tested by this procedure for a period of 132 hours (5.5 days) and 103 hours (4.3 days), respectively. Tap water samples were also collected and analyzed for background concentrations of lead.

Preliminary Findings from Laboratory Testing

Preliminary stagnation test results showed that passivation, as marked by a reduction in lead concentration to <10 ppb, generally occurred within the first 48 hours of stagnation (HDR/EES 2005). Several of the low-lead brass bubblers experienced periodic lead spikes, which could be attributed to releases of particulate lead. For the stainless steel bubbler, particulate release and/or passivation appeared to occur within less than 30 hours. Preliminary results of flow-through tests for both types of bubblers showed that particulate removal and/or passivation (lead concentration drops to <10 ppb) occurred within approximately four hours of starting the test (HDR/EES 2005).

Preliminary stagnation test results for brass elbow connectors showed that lead releases on the order of 800 and as high as 1,400 ppb occurred during the initial 65 hours (2.7 days) of the test (HDR/EES 2005). Passivation to a lead concentration in the range of 200 to 400 ppb occurred after 140 hours (5.8 days) of exposure in these preliminary findings. Preliminary stagnation test results for flex connectors with brass ends showed that the initial lead releases on the order of 110 up to 250 ppb occurred during the initial 48 hours of the test (HDR/EES 2005). Passivation to a lead level of about 15 ppb occurred at 265 hours (11 days) in these preliminary tests. The surface area of these elbow and flex connectors is very small, minimizing their relative lead contribution. Average lead concentrations from these fittings proportional to a 250 mL samples were 3.75 μg/L for the flex connectors, 50 μg/L for the brass elbow connectors, and 25 μg/L for the brass shut-off valve. The district response to these results was to eliminate brass components in the system.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Summary

The Seattle Public Schools has conducted extensive field and laboratory testing of endpoint devices and are completing a series of remediation efforts to provide safe and aesthetically pleasing water in their facilities. A variety of remediation measures have been implemented, including replacement of components, installation of point-of-use filters, shutting off non-compliant sources, and pre-conditioning components prior to installation. Pre-conditioning components by flushing prior to installation was demonstrated to be one of the best solutions to reducing metals release from these sources.

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Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

RWE Thames Water
London, UK
AwwaRF Project 3018 Case Study

Utility Profile

Source water	Rivers (75%) Groundwater (25%)
Surface treatment	chemical coagulation, filtration, granular activated carbon adsorption, ozonation and disinfection
Corrosion control treatment	Varied, but primarily phosphoric acid
Daily demand	Varies by supply area
Total customer population base	7 million
Service line ownership	Water companies own the part of the service from the water main in the street up to the stopcock at the boundary of the property
Lead service lines	Varies by Water Company
Type of replacement program	Varies by Water Company. In the UK, reductions in plumbosolvency by chemical treatment are maximized before lead pipe replacement is undertaken.

PLUMBOSOLVENCY CONTROL AT THAMES WATER

Thames Water is the largest water and wastewater services company in the United Kingdom, supplying domestic and commercial customers in London and the Thames Valley. Thames Water provides water services to over seven million customers and wastewater services for nearly 12 million customers in the UK alone. Three quarters of water supplies are derived from rivers while the remainder comes from groundwater sources. Table B.10.1 outlines the water quality parameters for surface water and groundwater sites within the Thames Water Region.

Water is treated by a variety of processes including chemical coagulation, filtration, granular activated carbon adsorption, ozonation and disinfection. The supply area within the Thames region is divided into a number of water supply zones where sampling for a range of water quality parameters is performed from fixed and random locations.

Table B.10.1
Typical Water Quality for Thames Water Region Sources

Parameter	Surface water	Groundwater
pH	7.1-7.9	7.1-7.4
Alkalinity	134-223mg/l as CaCO3	230-290mg/l as CaCO3
Turbidity	<0.1NTU	<0.1NTU
Total organic carbon	2.0 mg/l	0.6-0.8mg/l

It is estimated that there are approximately 1.4 million lead service pipes still in operation within the Thames region equating to approximately 7200km of pipe. A significant proportion of the mains distribution network within the Thames region consists of cast iron pipes some of which date back over 100 years. Of these the majority are joined using a lead run joints which consists of a bell and spigot casing at opposite ends of the pipe that is held in place by a yarn and lead mechanical joint. Due to the age of the water mains many of these joints have corroded and leaching of lead is no longer considered an issue. Virtually all contamination at customers taps arises from lead service pipes, lead-lined tanks, lead solder joints and leaded copper alloy fittings.

Thames Water has an obligation to inform customers if random daytime samples have revealed high levels of lead at customer's taps. All customers contacting the Customer center concerned about lead will have their properties sampled with a 30 minute stagnation sample.

To assess which water treatment works should be included in the regulatory programme for plumbosolvency control, works were allocated into groups based on the areas they served. To be included in the programme of plumbosolvency the combined non-compliance at 10 μg/l had to be greater than 5%. A phased programme of orthophosphoric acid dosing was introduced at 44 treatment works in the Thames region between 2001 and 2003. Installation of the plant was complete by the end of 2002, with the target phosphate level being achieved by March 2003. The initial phosphate target doses were based on laboratory experiments and vary from works to works. Concentrated orthophosphoric acid from bulk supply is diluted to the required concentration in a dilution tank. When the dilution tank is full a recirculation pump mixes the acid for 1 hour before a dosing pump pumps diluted acid into a carrier waterline which is then transferred to the main works flow. The acid is delivered as a batch process rather than continuous feed and is dependant on the background level of phosphate and the works flow rate. The recommended dose for surface waters was set at 1.5-2 mg/l and for groundwater 1.0-1.2 mg P/l. Incremental increases of 0.5-0.6 mg/l orthophosphate was used to minimize effects on water quality. Once the initial target was achieved results of sampling from customers' taps and lead rigs determined whether phosphate doses needed to be changed. At surface treatment works where phosphate levels in raw water may vary seasonally, changes to the applied dose are made so that the target concentration in supply remains stable. Dosing was added to the water treatment process prior to disinfection. The optimum pH for phosphate dosing was 7.2-7.8 based on accepted knowledge. Although pH stability was considered to be an important factor in the overall success of dosing maintaining a stable phosphate dose at treatment works was essential. The impact of orthophosphate dosing on customers within the Thames Water region was examined in detail. The hardness of the water within this region had led to the development of scale on domestic utensils. Concerns over the sudden removal of scale from kettle elements and the appearance of water after boiling prompted a number of research projects to examine the possible impact on customers. Different levels of phosphate were used to examine the stability of scale on kettle elements, taste, odour and appearance of boiled water. Whilst the results demonstrated that scale could be formed at high phosphate doses no customer complaints related to phosphate were recorded.

The companies approach to monitoring was by taking samples by RDT, Stagnation and lead rigs. RDT for lead and phosphate residuals at the customer tap are additional to statutory monitoring samples. In addition 30min stagnation samples at fixed properties where plumbing has been confirmed to be lead are also taken in the earlier stages of dosing. These samples were taken three times in one week per month. There was a minimum of three customer properties per group of works. In total there were 67 Captive customers where 30min stagnation samples are taken. In addition there are 41 lead rigs in operation at treatment works and in distribution. 14 of these lead rigs are located at treatment works while 27 remained in distribution.

Statutory (RDT) sample monitoring had shown that there was no significant reduction in the number of samples failing the lead standards in 2002 as compared to 2001. This was probably due to the fact that some of the larger treatment works did not have plumbosolvency treatment installed until late 2002. Dosing also began at a sub-optimal level to avoid adverse customer reaction.

During 2003 seasonal factors made interpretation of some groups difficult, as higher lead levels had been recorded during the summer months because of higher water temperatures, which will cause lead to dissolve more readily. During 2004 this seasonal variation had again been observed within a number of groups over the summer period with an increase in failures observed during the warmer months of June, July and August. Figure B.10.1 shows the correlation seen between temperature and lead levels at a Lead rig situated at a treatment works in west London. This shows that lead increases on a seasonal basis. Plumbosolvency is seen to be reduced as the phosphate reaches its target dose.

A review of the statutory and operational monitoring for lead, carried out during 2003 and 2004 in the water supply zones, fed by works where dosing was occurring indicates that most areas were showing a reduction in the lead levels observed at customers taps. Each treatment works where dosing was occurring fell into one of 15 schemes outlined in Table B.10.2. The size and source water differs within and between schemes and also at different times of the year. In some groups the response to orthophosphate dosing had been very quick and dramatic whereas other groups have been slower to respond. Although overall compliance is above 95% (10µg/l) specific hot spots within a proportion of these lead zones still occur.

Group 1-15 serve populations ranging from approximately 30,000 to almost 5 million. The level of non-compliance at 10•g/L before plumbosolvency control ranged from 5.54-16.48% of samples. Implementation of treatment during 2002 and subsequent data collected in 2003 revealed that the level of non-compliance was significantly reduced and by 2004 all groups were within the 95% compliance target set by the DWI. Further optimization was observed in 2005 and 2006 with several groups observing no failures. However it is recognized that although the level of compliance is high there remain a number of hot spots within some of these regions where individual measurements at customer's taps remain high.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

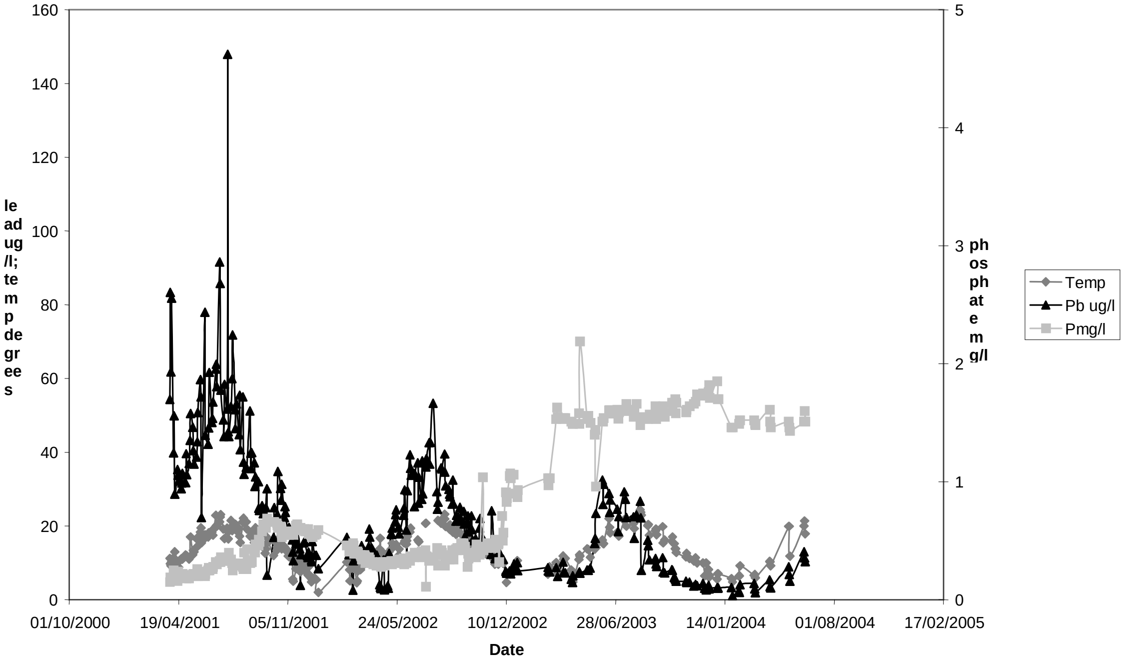

Figure B.10.1 Relationship between temperature and lead levels at treatment works X.

From the 15 groups outlined above three have been selected as case studies for further discussion. These are groups 4, 9 and 11.

Case study 1: Group 4

Group 4 consists of three water treatment works (Table B.10.3), which feed 5 water supply zones that serve a total population of 181, 732 (in 2004). Phosphate dosing at the three treatment works were commissioned between Feb 2002 and November 2002 with an optimum target phosphate dose of 1.0mg P/l. At two of the treatment works the commissioning concentration was 0.5mg P/l. This was increased to 1.0mg P/l in August 2002.

Table B.10.2
Percent (%) lead non-compliance with 10•g/L standard within the 15 lead groups or schemes in the Thames Water region.

Group No	Estimated Population 2004	Pre-dose data % > 10•g/L lead 1991-2001 *	Post dose data 2003 % > 10•g/L lead	Post dose data 2004 % > 10•g/L lead
1	177,979	16.48	3.83	4.31
2	390,185	10.67	3.35	2.94
3	74,570	12.84	4.17	3.51
4	181,732	12.43	6.00	1.89
5	125,469	7.61	12.50	0.94
6	579,960	7.69	5.54	6.50
7	50,407	8.43	0.00	0.00
8	265,785	6.46	1.08	1.45
9	241,361	7.17	2.27	4.77
10	165,285	5.54	4.08	0.00
11	44,343	11.86	0.00	0.00
12	27,584	7.5	0.00	0.00
13	30,900	6.93	3.80	0.00
14	30,515	5.88	6.25	1.72
15	4,821,268	9.97	6.56	4.27

Table B.10.3
Target phosphate dose for treatment works within group 4

Treatment works	Target phosphate dose	Date commissioned
A	1mg/l	March 2002
B	1mg/l	February 2002
C	1mg/l	November 2002

At each of these treatment works water is abstracted from a number of boreholes and after pressure filtration is mixed. Water may then filter through granular activated carbon absorbers, is prechlorinated using chlorine gas and dechlorinated using sulphur dioxide.

Lead data collected prior to dosing consisted of 1263 random daytime samples taken between 1996 and 2001. 4.04% (51 samples) of these samples exceeded the 25•g/L standard while 12.43% (157 samples) exceeded the 10•g/L standard. After commissioning of orthophosphate dosing in 2002 sampling for monitoring plumbosolvency control began in 2003. The total number of random daytime samples taken in 2003 was 300. 5% of these samples exceeded 25•g/L while 6% remained above 10•g/L. A significant improvement in 2004 was observed with only 1 sample out of a total of 264 exceeding 25•g/L and only 1.89% of samples exceeding 10•g/L. In 2005 and 2006 non-compliance remained below 2%.

Thames Water had 6 fixed customer properties (only monitored from 2001-2004) and 5 lead rigs for this lead group. The fixed properties were confirmed as having lead pipe work. 30-minute stagnation samples were taken 3 times a week from each property. Lead rigs comprised 3 meters of new lead pipe with an automatic water flow. 1 Litre water samples were collected for

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

analysis. The results obtained from 30-minute stagnation samples at 5 fixed properties are shown in Figures B.10.2- B.10.6. Customer properties were also analyzed for temperature and phosphate levels. At fixed property no. 1 early phosphate dosing is inconsistent and large variation in lead levels occur. In addition lead levels increase with increases in temperature. However after stable phosphate levels are maintained throughout 2003 to the end of 2004.

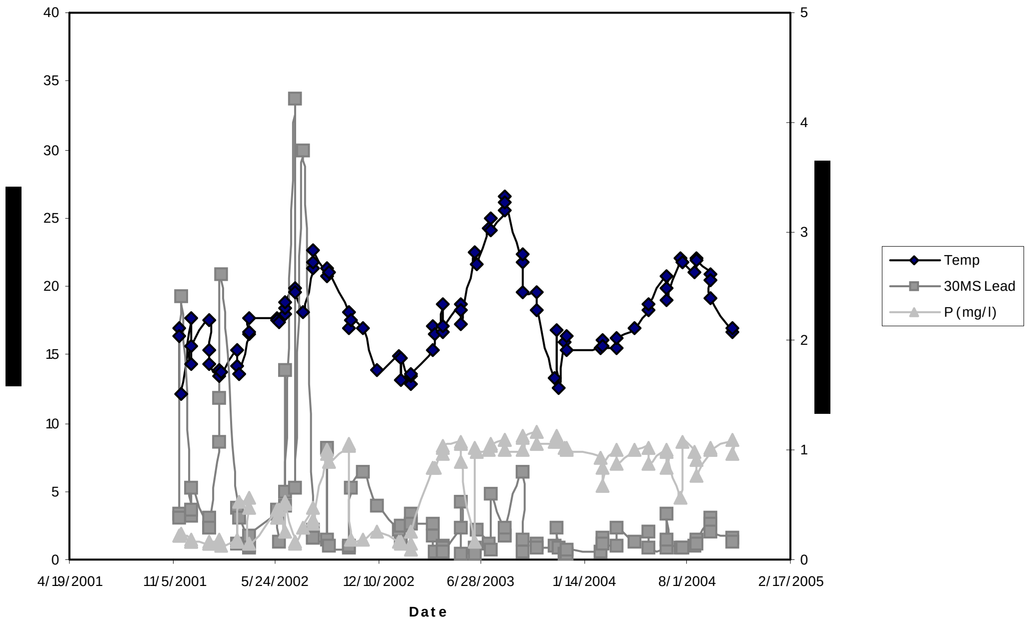

Figure B.10.2 Lead and phosphate levels from 30 min stagnation samples at Fixed customer property 1 during 2001-2004

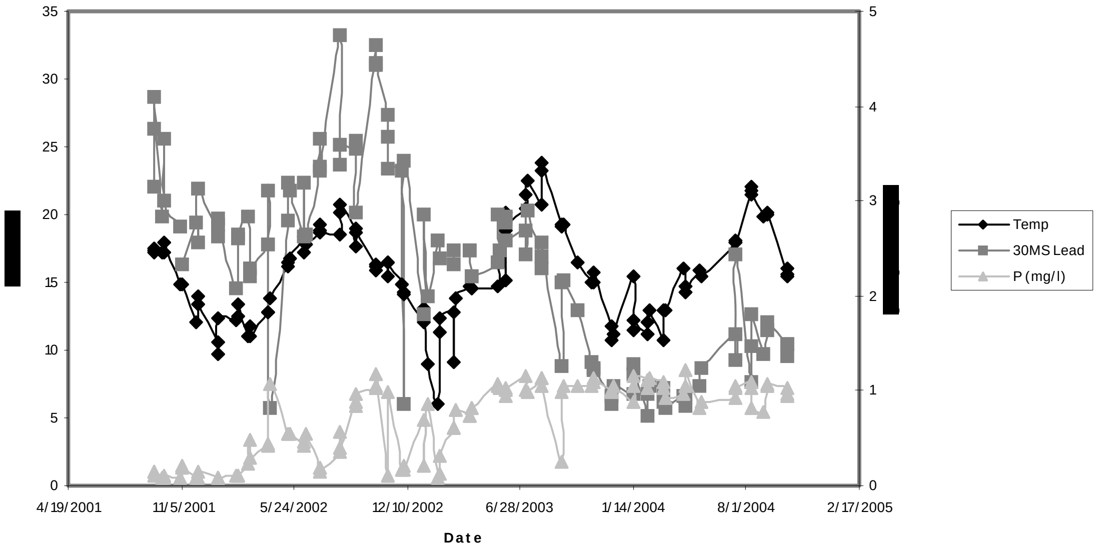

Figure B.10.3 Lead and phosphate levels from 30 min stagnation samples at fixed customer property 2 during 2001-2004.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

The trend in lead levels observed at property 2 (Figure B.10.3) followed the same temperature profile. As temperature increased lead levels increased and as the temperature dropped lower lead levels were detected. Higher lead levels were observed at property 2 compared to property 1. Lead levels started to decline as the phosphate dose reached 1mg/l and the majority of samples remained below 10•g/L. At property no. 3 lead levels were variable even after phosphate dosing levels increased. The increases appear to follow seasonal temperature changes.

The lead levels detected at the customer tap of property 4 (Figure B.10.5) and property 5 (Figure B.10.6) are higher that that observed at other properties tested even though phosphate levels are maintained in the distribution system. Lead levels range from 5•g/L to 13•g/L in the second half of 2004 at property 4 and 1.9-21•g/L at property 5. The highest lead levels detected correlated with higher temperatures. The results from the samples taken at customer's properties show that the 1mg/l phosphate target has generally been obtained.

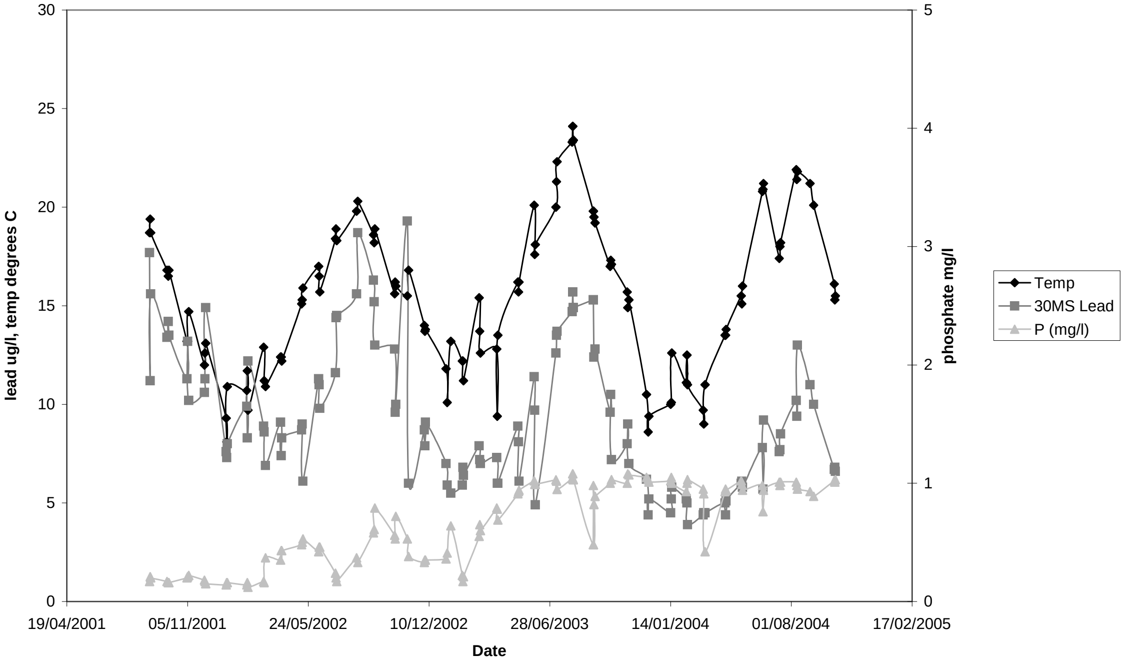

Figure B.10.4 Lead and phosphate levels from 30 min stagnation samples at fixed customer property 3 during 2001-2004.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

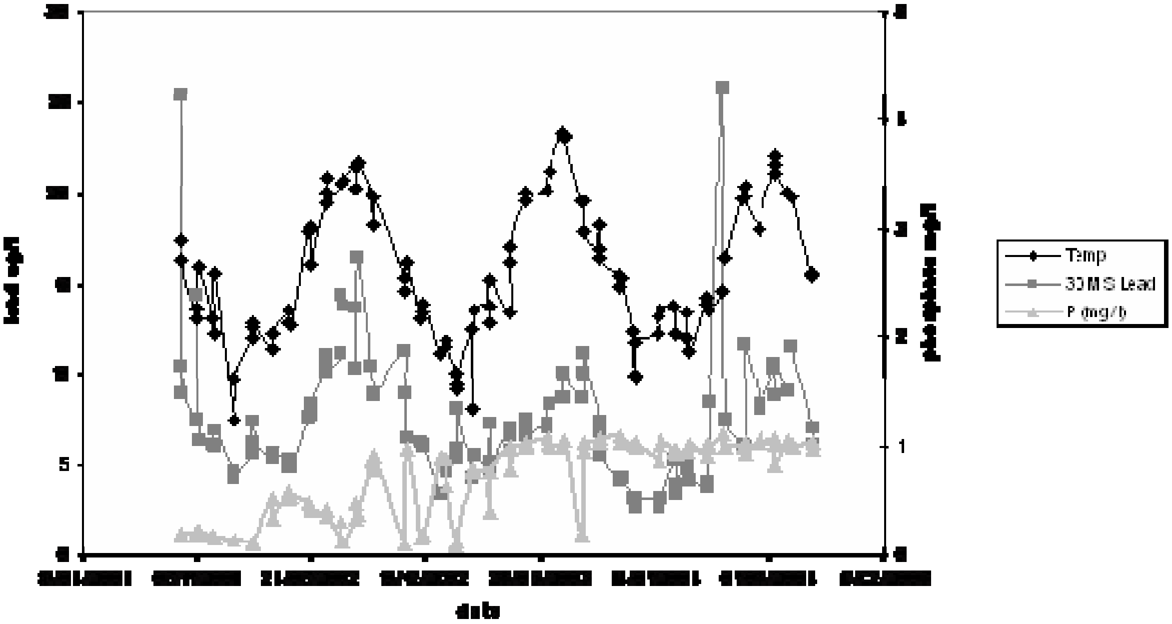

Figure B.10.5 Lead and phosphate levels from 30 min stagnation samples at fixed customer property 4 during 2001-2004.

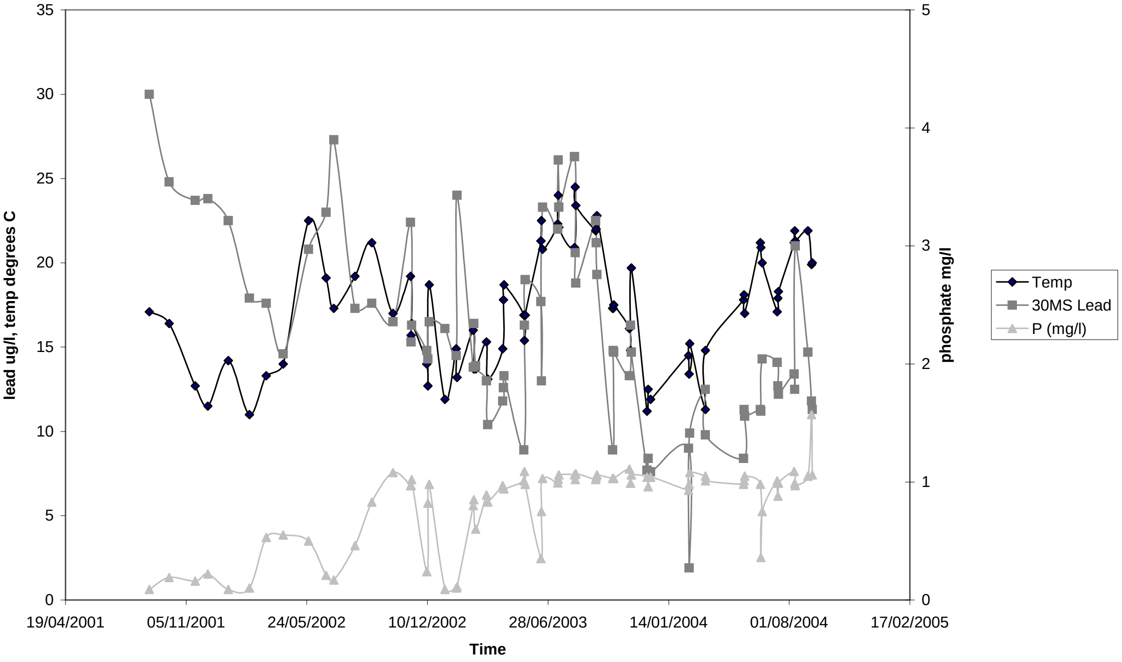

Figure B.10.6 Lead and phosphate date for customer property no. 5 for 2001-2004

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Thames water also had 5 lead rigs that are routinely monitored for lead. Graphs showing the lead and phosphate levels over time are presented in Figures B.10.7- B.10.11.

From the lead rig sampling data lead levels before dosing were detected as high as 250 •g/L. The consistency of orthophosphoric acid dosing was poor at the initial stages of plumbsolvency treatment and led to unstable levels of lead. As dosing became more stable and reached a consistent level of 1mg P/l the levels of lead decreased dramatically. The levels observed have been consistently low but not always below 10 •g/L.

Case study 2 Group 9

Group 9 consists of 1 water treatment works, which feeds into 10 water supply zones. The AWT is designed to treat up to 121 Ml of water per day from a total of ten boreholes. The raw water is filtered through GAC contactors, aerated and then dosed with sodium hypochlorite. Orthophosphate is added with the hypochlorite dosing for Lead Control in distribution supply pipes. Treated water from the contact tank is de-chlorinated by dosing with sodium bisulphate.

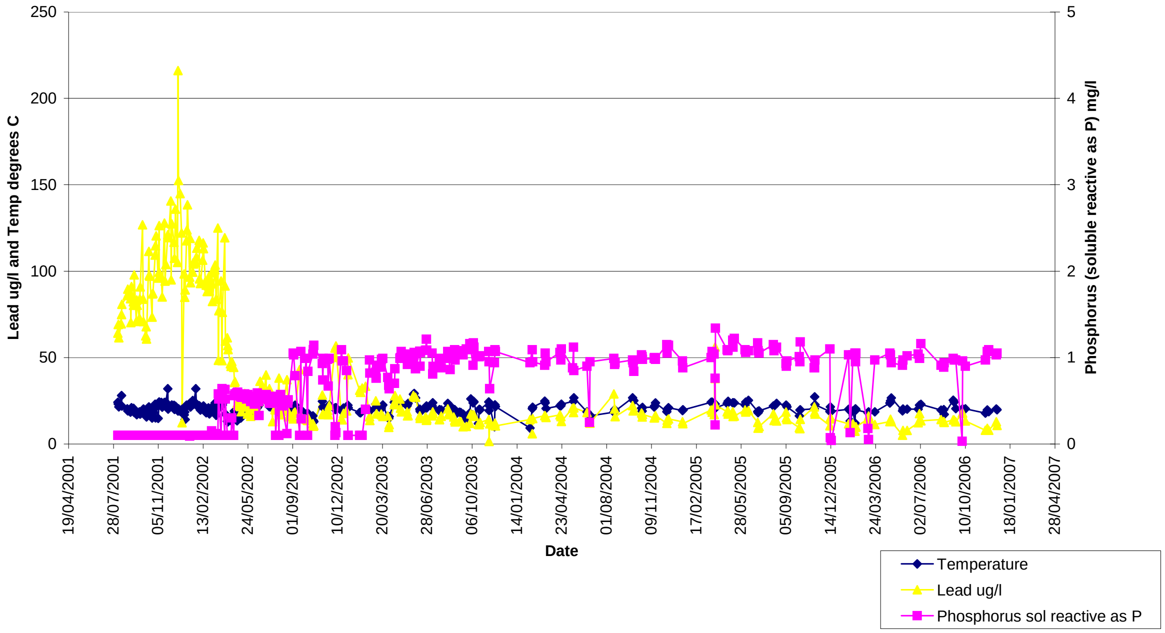

Figure B.10.7 Lead and Phosphate levels observed at Lead rig 1 2001-2004

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

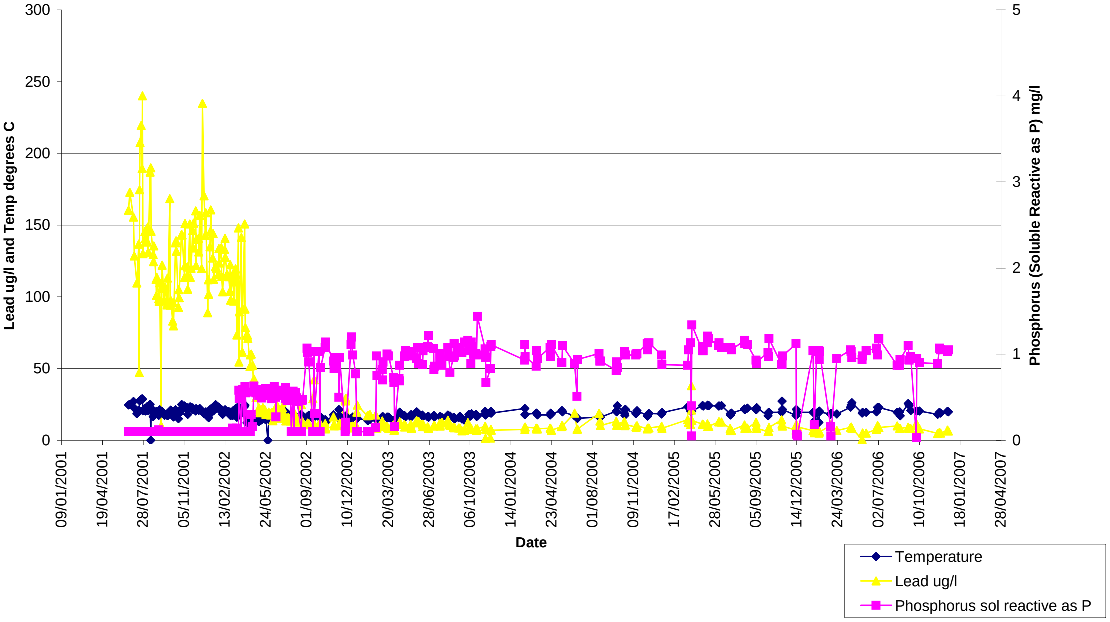

Figure B.10.8 Lead and phosphate levels observed at lead rig 2 for 2001-2004

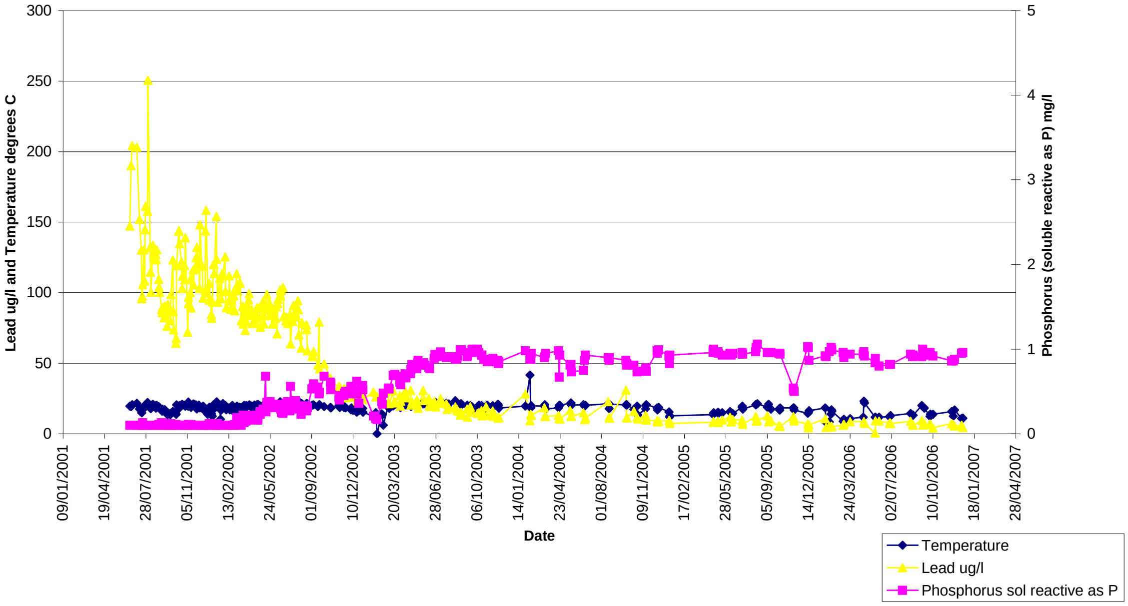

Figure B.10.9 Lead and Phosphate levels observed at Lead rig 3 for 2001-2004

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

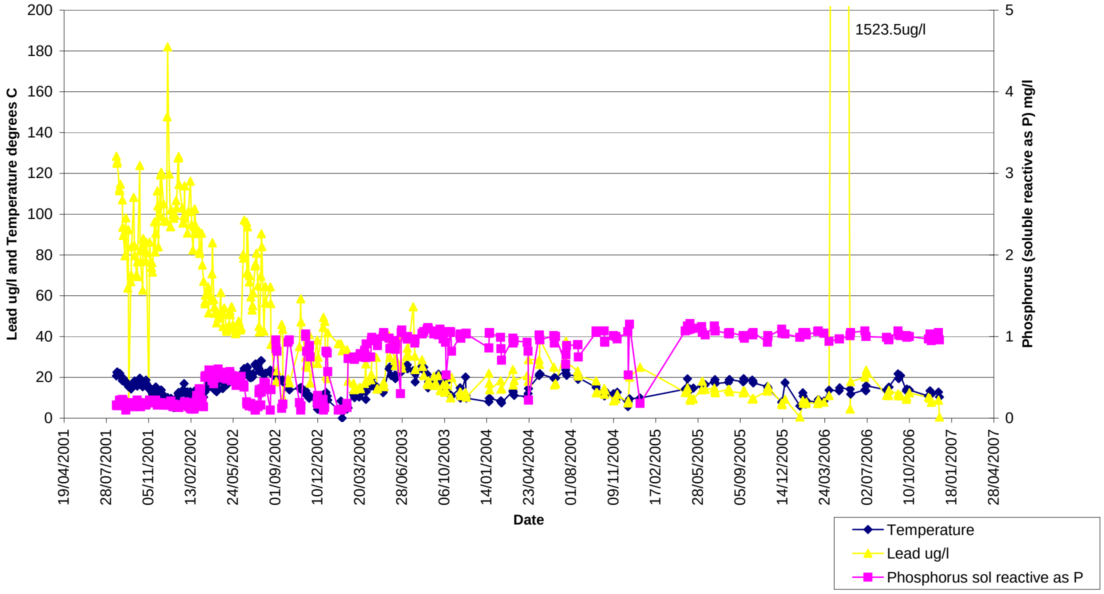

Figure B.10.10 Lead and Phosphate levels observed Lead rig 4 for 2001-2005

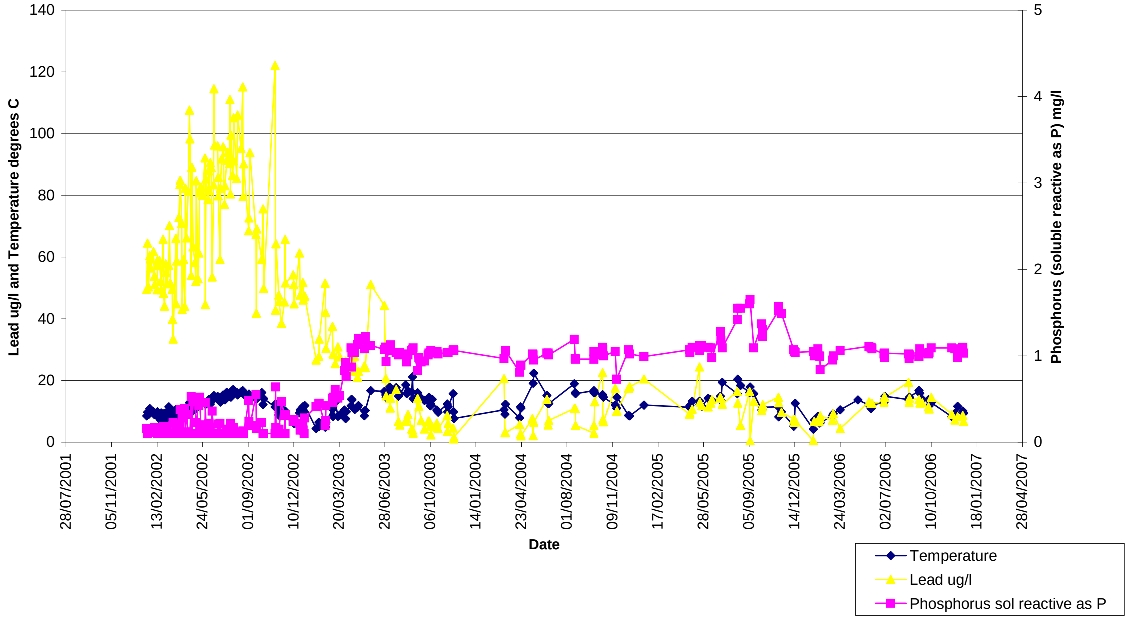

Figure B.10.11 Lead and Phosphate levels observed at Lead Rig 5 2001-2004

The area supplied by this group serves a population of 241, 361 (2004). Dosing began in August 2002 with a target dose of 1mg/l phosphate. Figure B.10.12 displays the phosphate dosing at the water treatment works. Pre dosing RDT data taken between 1992 and 2001 comprised of 307 samples. The total number of samples exceeding the 25 •g/L standard was 8 while the no of samples exceeding 10 ug was 22, representing 7.17% of the total no. of samples

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

taken (Figure B.10.13). Sampling data for 2002 is not included as installation of orthophosphate equipment and commissioning of equipment occurred. During 2003 the number of RDT samples taken was 44 of which 2.27% of samples exceeded the 10 •g/L standard. It is likely that with an increase in sampling data would have detected a greater no. of samples exceeding this level. In 2004 the number of RDT samples taken was 482 with the non-compliance at 10•g/L at 4.77%. In 2005 significant improvements were observed with only 1.84% of samples failing the 10 •g/L standard. Non compliance increased slightly in 2006 to 2.4% of samples.

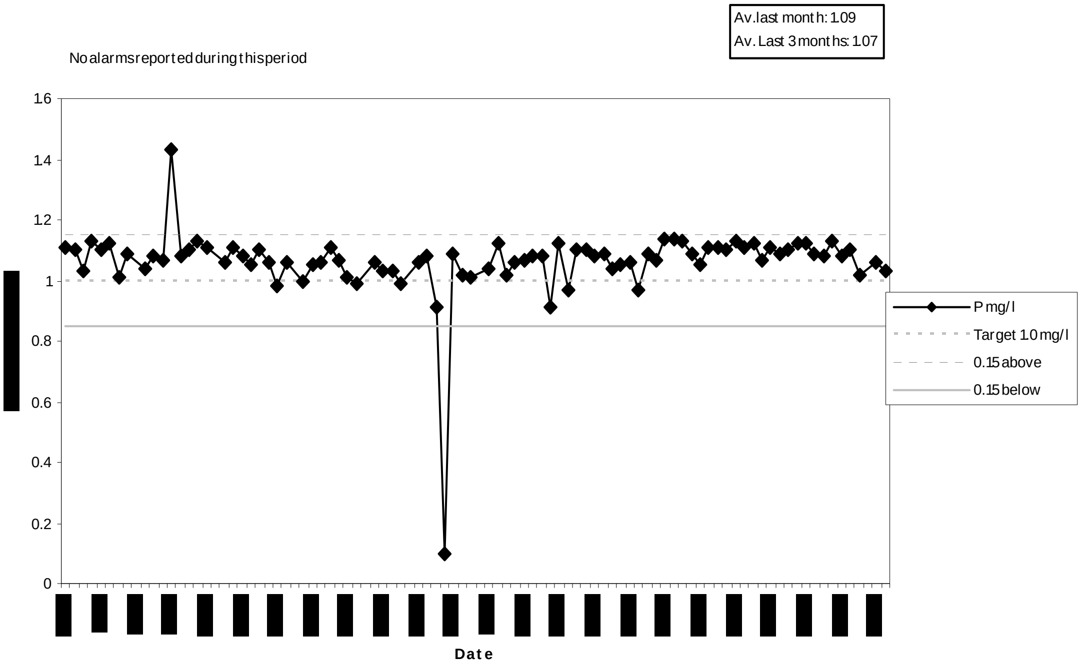

Figure B.10.12 Phosphate dosing at Group 9 WTW during 2004

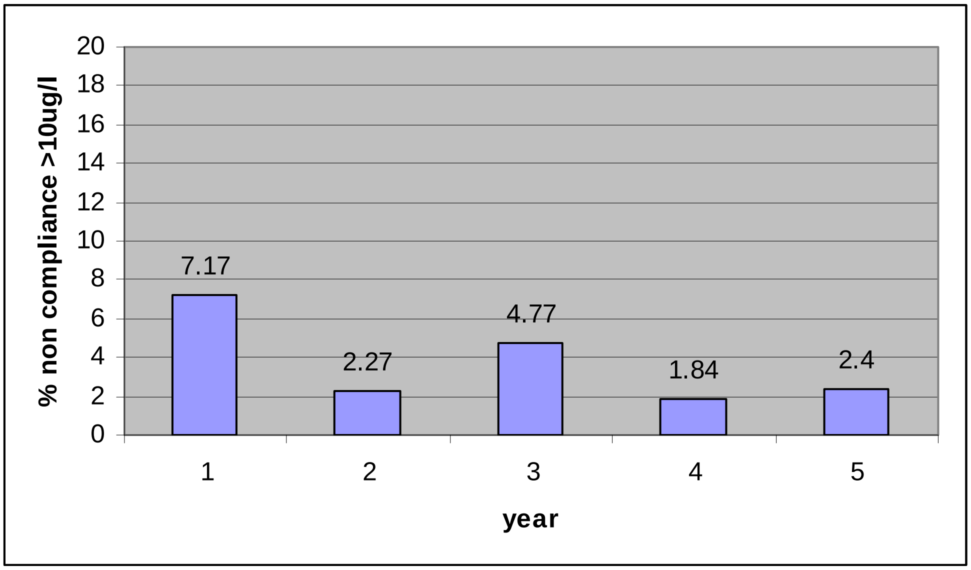

Figure B.10.13 Percent (%) of samples non-compliant at 10•g/L and 25ugPb/l for Group 9 - Case study 2

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Case Study 3 Group 11

Group 11 consists of two water treatment works feeding into two water supply zones. The supply area serves a population of 44,343 in 2004. One of the WTW abstracts directly from river water but water may also be abstracted from boreholes. Raw river water is pumped from the intake works, pre-chlorinated, pH adjusted, mixed, and then fed to clarifiers. After pH re-correction, water then enters dual media conventional Rapid Gravity Filters. Borehole water enters the process stream at the Rapid Gravity Filter inlet channel. Process water is pumped from the RGFs to Granular Activated Carbon Absorbers. The water is disinfected using the super and de-chlorination method. Sodium hypochlorite is dosed before the water enters the contact tank and then de-chlorinated using sodium bisulphite. The second treatment works within this group is a groundwater treatment works that consists of 2 on-site boreholes. The abstracted raw water is treated on site by the super chlorination and de-chlorination disinfection technique.

Both treatment works had a target dose of 1mg/l phosphate and dosing began in September 2002 and November 2002 respectively.11.86% of samples (177 in total) between 1991 and 2001 exceeded the 10•g/L lead level while 4.52% of samples exceeded the 25•g/L lead standard. 49 samples taken in 2003 and 103 samples taken in 2004 were all within the 10•g/L standard and therefore this group is 0% non compliant. This trend continued throughout 2005 and 2006 with full compliance observed.

CONCLUSIONS

Recent (2004) audits of UK water companies by the Water Quality Regulator (DWI) have shown that plumbosolvency control measures through pH adjustment and orthophosphate dosing are reducing lead in water (as measured at customers taps) to below the 10•g/L level in many regions with different water compositions. For some companies, reduction in lead to its lowest possible level has taken longer than expected and further reductions are thought possible. The key control parameters for optimum lead level reduction are maintaining consistent dosing into the distribution system at the appropriate phosphate level for that water composition.

Orthophosphate dosing has been successfully installed and commissioned within the Thames Water Region. The impact of dosing on lead levels in distribution has been significant. Some areas have shown a quick response to treatment while others although 95% compliant at 10ugPb/l have a number of ‘hot spots’ where lead levels remain high. In an attempt to understand lead compliance and why failures occur specific water treatment processes and practices are currently under review.

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DWI Information Letter 12/2000 Determination of requirements to meet new lead standards.

DWI Information Letter 3/2001 Further guidance on requirements to meet new lead standards.

UKWIR report ref 99/DW/04/6 The impact of service pipe replacement on Leakage.

UKWIR report ref 99/DW/04/8 Concentration of lead at Customer's taps: Trends in monitoring data 1990-1998.

UKWIR report ref 98/DW/04/5 Concentration of Lead at Customer's taps: Trends in monitoring data 1990-1996.

UKWIR report ref 99/DW/04/7 Customer survey information on lead in the public domain.

UKWIR report ref 97/DW/04/2 Concentration of lead at customers taps. A statistical approach.

UKWIR report ref 97/DW/4/1 Approaches for controlling plumbosolvency.

UKWIR report Unpublished. Demonstrating the effects of water treatment to reduce lead concentrations.

UKWIR report Unpublished. Operational guidelines to meet quality regulators expectations at optimum cost. Optimisation of lead reduction strategies and development of acceptable regulatory assessment techniques.

WRC report DWI 6173 Unpublished. Demonstration of Optimisation of Plumbosolvency Treatment and Control Measures.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

APPENDIX C

PILOT EVALUATIONS OF LEAD SOURCE CONTRIBUTIONS

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

LABORATORY AND PILOT EVALUATIONS OF LEAD SOURCE CONTRIBUTIONS

INTRODUCTION

This appendix contains the results of laboratory and pilot evaluations of lead level contributions from various lead containing materials, including residential brass kitchen faucets (Portland Water Bureau), meters (Seattle Public Utilities), and lead service lines (Washington Aqueduct).

EVALUATION OF RESIDENTIAL BRASS KITCHEN FAUCETS AT THE PORTLAND WATER BUREAU

A 12-month study of six commercially available residential brass kitchen faucets was conducted to determine lead and selenium leaching at various stagnation times as well as during continuous long-term simulated residential use. The evaluation was conducted at the Portland Water Bureau's Water Quality Laboratory. The faucets were selected to represent varying lead content and included one faucet manufactured with Envirobrass, a brass alloy with a lead content of less than 0.25%.

Objectives

Five agencies contributed to the faucet-testing program: the Portland (Oregon) Water Bureau (PWB), the Copper Development Association (CDA), the NSF International, Inc. (NSF), the Virginia Polytechnic Institute and State University (Virginia Tech), and the University of Cincinnati (UC). The overall objective of the PWB faucet-testing program was to conduct 12 months of laboratory evaluation activities that quantified the amount of total lead released into drinking water by different brass residential kitchen faucets containing varying levels of lead. Specifically, the PWB activities examined the:

- Impact of varying stagnation periods on lead leaching.
- Lead leaching from new brass faucets after a 6-hour water stagnation period.
- Changes in lead levels under different sampling flow rates.

The CDA's objective was to identify which of the numerous components inside the PWB-selected brass kitchen faucets contained the lead that could be leached into drinking water, while the NSF analyzed the faucets per the ANSI/NSF Standard 61, Section 9 protocol to provide a comparison between the long-term testing results with the results of Standard 61 testing. Virginia Tech provided analysis of the potential accumulation of lead particles, as well as other metals, on the PWB faucet aerators after the twelve month period was completed. Finally, UC analyzed the scale formation on the internal brass components at the conclusion of the twelve-month testing.

Testing Schedule

The central part of the faucet analysis for this project was the twelve-month testing at the PWB. During this period, several tests were conducted to determine the lead leaching behavior of faucets. Some of these tests were replicated during the testing duration to determine any changes over time. Meanwhile, the CDA and NSF activities were conducted in parallel to the

PWB activities. UC and Virginia Tech began their analysis once the PWB testing was completed.

Methods and Materials

This section describes the methods and materials used by the PWB, CDA, NSF, and Virginia Tech. Scale analyses methods can be found in Appendix G.

Portland Water Bureau Testing

The faucet experiments conducted at the PWB consisted of six faucets installed in a test rig located in the PWB Water Quality Laboratory. The laboratory receives drinking water from the Bull Run Watershed, which is an unfiltered surface water source, which can be augmented with groundwater. The faucet experiments used this water. Table C.1 lists the quality of this water during the testing period. For the majority of the testing, the water was solely from the Bull Run Watershed. The last two months of testing saw the water quality change to include a blend of surface water and groundwater.

Table C.1
Water quality measured entering the PWB test rig

Parameter	Unit	Oct. 4, 2005 to Aug. 17, 2006[a]		Sept. 7, 2006 to Nov. 17,2006[b]	
		Average	Range	Average	Range
Alkalinity, Total as $CaCO_3$	mg/L	10.0	4.5 – 14.0	48.5	21.0 – 98.0
pH	S.U.	7.4	6.8 – 7.9	7.7	7.3 – 7.9
Conductivity	μS/cm	35.3	25.0 – 45.5	114.9	64.5 – 204
Chlorine, Free	mg/L	0.06	0.01 – 0.14	0.06	0.03 – 0.10
Chlorine, Total	mg/L	1.0	0.2 – 1.3	0.8	0.5 – 1.0
Temperature	deg. C	17.9	12.3 – 23.2	17.9	15.6 – 20.2
Lead, Total	μg/L	<0.001	<0.001 – 0.003	<0.001	<0.001 – 0.004
Selenium, Total	μg/L	<0.001	<0.001 – 0.006	<0.001	<0.001

Notes:

a. Corresponds to Days 0 to 264 for long-term PWB testing
b. Corresponds to Days 285 to 359 for long term PWB testing

Test Rig

The test rig consisted of six faucets mounted side-by-side for concurrent testing. Figure C.1 shows a schematic of the rig. Figure C.2 is a picture of the test rig with the faucets attached. The distribution piping consists of ½-inch and ¾-inch diameters PEX tubing and plastic fittings obtained from a local hardware store and acid washed to remove any manufacturing oils or other contaminants. Each faucet was connected on the cold water (CW) side to the distribution piping using the connectors provided in the respective faucet’s packaging. The hot water (HW) side of the faucets was plugged and not used. Water from the faucets discharged to a plastic gutter that drained into an adjacent sink.

Flow control to the entire rig was controlled with an automatic solenoid valve (for on/off control) and a rotameter (for flow rate control). The internal solenoid valve body was plastic, with no metal contacting the water. The rotameter was constructed with a plastic body and stainless steel rod, weight, and valving. The contribution of the stainless steel to the lead results was estimated to be negligible. Flow through the individual faucets for sample collection was controlled using the faucet valve handles.

The length of the plumbing between the service main and the laboratory was quite long. Due to the plumbing length, which could result in water with long water age and low to no chlorine residual entering the faucet test rig, a second solenoid valve was added to flush the stagnant water from the internal plumbing and ensure that fresh water from the water main was passed through the faucets.

Faucet Selection

The original intent in selecting the faucets for installation in the test rig was to poll manufacturers on the lead content in brass used in their respective residential kitchen faucets. However, the polling did not provide enough information to select the faucets. As a result, seven faucets were purchased for an intensive stagnation testing. First, each faucet had the aerators removed and then flushed at the maximum flow rate with 15 gallons of PWB tap water each to remove any residual contaminants from the faucet manufacturing. Afterwards, each faucet was filled with untreated Bull Run water, a relatively low pH, low alkalinity water that is more conducive for lead leaching. The water was analyzed at the end of a 24-hour stagnation period for total lead.

Figure C.3 shows the lead results from the 24-hour stagnation and Table C.2 describes the faucets ultimately selected for subsequent use in the test rig and their corresponding placement order in the rig. Three faucets were selected based on the results of the intensive stagnation testing. A duplicate of the faucet with the highest detected lead was selected to determine the variability of lead release for this type of faucet. The fifth faucet was manufactured with Envirobrass, a brass alloy that uses selenium and bismuth in place of lead. The maximum lead content in Envirobrass is 0.25% weight/weight as opposed to 1.5 – 7% lead in brass commonly used for residential plumbing fixtures (Copper Development Association 2000). The final faucet was labeled as California Proposition 65 compliant, meaning that it meets the lead testing requirements of ANSI/NSF Standard 61, Section 9 (NSF 1994), however instead of being certified using a Q statistic of 11 μg, it must meet a more restrictive Q statistic of 5 μg for residential kitchen faucets (AwwaRF, 2007, Weil 2005). Figure C.4 shows pictures of the selected faucets.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

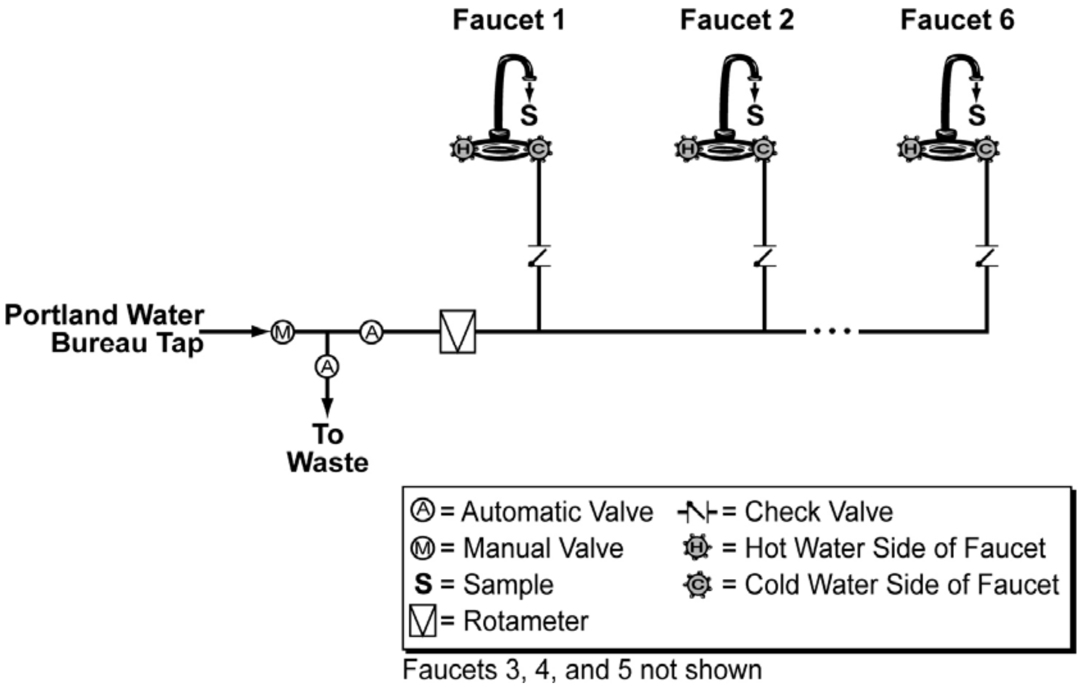

Figure C.1 Portland Water Bureau test rig schematic.

Figure C.2 Portland Water Bureau faucet test rig.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

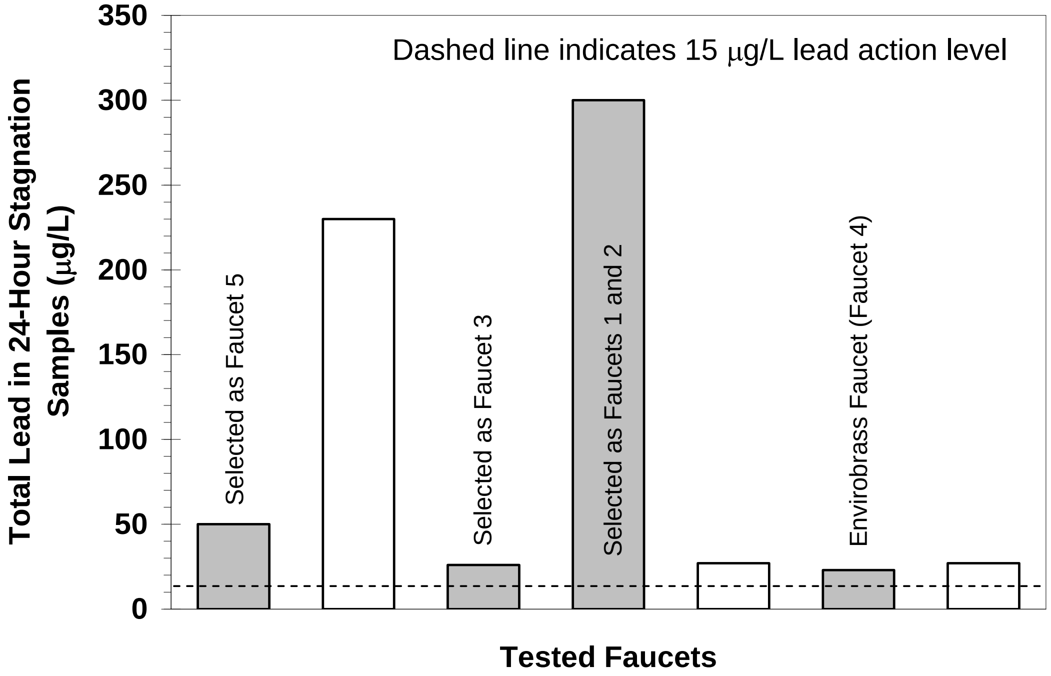

Figure C.3 Results of faucet identification using 24-hour stagnation with untreated Bull Run water.

Table C.2
Faucets Selected for Installation in PWB Test Rig

Faucet	Manufacturer	Number of Handles	Internal Volume (mL)	Comment
1	A	1, on main body	201	Leaded brass with highest lead concentrations detected
2	A	1, on main body	201	Duplicate of Faucet 1
3	B	1, on main body	171	Leaded brass with lowest lead concentrations detected
4	C	2, on main body	134	Specifically manufactured with the EnviroBrass alloy
5	D	1, separate from body	162 (total): Handle – 29 Spout body - 133	Leaded brass with lead concentrations closest to the detected range mean. The two pieces were hydraulically connected to each other using ~5 cm of ½” diameter PEX tubing
6	E	1, on main body	95	Leaded brass faucet that mentions compliance with California Proposition 65 on the product literature. Pre-selected based on literature; not tested with 24-hour Bull Run water stagnation

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Figure C.4 Faucets selected for Portland Water Bureau testing.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

PWB Test Schedule

As noted earlier, the faucets identified and installed in the PWB test rig were used in a series of tests. The schedule of the tests is listed in Table C.3.

Table C.3
PWB Faucet Testing Schedule

Date	Test	Comment
September 2005	Faucet identification and selection	Supplied tap water is 100% surface water
Oct. 2005	Impact of varying stagnation periods on metals leaching	First experiment
Oct. 2005 – April 2006	Leaching of lead and other metals after 6-hour stagnation period	Months 1-7 of service. Experiment stopped from Nov. 22 to Dec. 30.
April 2006	Impact of varying stagnation periods on metals leaching	Second experiment
April 2006	Differences from lead levels for various sampling flow rates	First experiment
May 2006 – Sept. 2006	Leaching of lead and other metals after 6-hour stagnation period	Months 8-12 of service. PWB switches water supply to blended surface water and groundwater in August.
Sept. 2006	Impact of varying stagnation periods on metals leaching	Third experiment
Oct. 2006	Differences from lead levels for various sampling flow rates	Second experiment
Oct. 2006	Faucets shipped to University of Cincinnati	PWB Testing ends

Copper Development Association Testing

CDA purchased duplicates of the faucets selected for the PWB to initially identify the metal composition of the individual faucet components. This identification consisted of sending the duplicate faucets to an independent laboratory[1] for metallurgical testing. The faucets were disassembled and then metal samples obtained from the cold water fitting, cold water tube, the lower and upper valve bodies, the spout receiver, and the spout. The samples were acid digested and then analyzed using an inductively coupled plasma mass spectrophotometer (ICP-MS). The results of the analysis are for the entire metal piece, and do not differentiate between the elemental metal composition at the wetted surface versus those compositions in the bulk metal or the non-wetted surfaces. Variations in metal compositions commonly occur between batches of metals used to make faucets. As a result, the data provided by these duplicates served as only initial guidance for identifying exact sources of lead within the faucet.

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[1] Stork Climax Research Services, Wixom, Michigan

NSF International Testing

NSF testing was conducted at the NSF laboratory in Ann Arbor, Michigan. This testing consisted of subjecting copies of the PWB-selected faucets to the testing procedures listed in NSF Standard 61, Section 9 (NSF International 2005). In summary, the testing protocol requires triplicates of the faucets to be tested over a 19-day period. The faucets are washed and then exposed to an extraction water (pH 8.0, 500 mg $CaCO_3$/L alkalinity, and 2 mg/L Cl_2) for 19 days using a static "fill-and-dump" test protocol. Sixteen-hour stagnation period samples are taken at nine sample days throughout the 19-day test for total lead analysis. Other metal contaminants are measured on the last day of the test. A statistical calculation is made based on the internal faucet volume, wetted surface area, geometric mean of the lead concentrations, the standard deviation of the concentrations, and a probability factor which is based on the number of products tested. A statistical Q value is derived from this calculation to represent the lead dose of the product. An endpoint device must have a Q value of $\leq$11 µg of lead to meet the requirements of the standard.

Virginia Tech Testing

The aerators were removed from PWB faucets upon conclusion of the faucet testing at the PWB and shipped to Virginia Tech. Virginia Tech analyzed samples of the metal deposits that had formed on the interior of the faucet aerator using an ICP-MS.

University of Cincinnati Scale Analyses

The six faucets from the Portland faucet rig experiment were tested at the University of Cincinnati (UC) for scale development and for effects of leaching on metal compositions. Methods and materials used in these analyses can be found in Appendix G.

Results and Discussion

This section describes the results of experiments conducted at the PWB, CDA, NSF, and Virginia Tech. The faucet experiments were conducted in multiple locations, at different times, and sometimes in parallel. The following section organizes the results of these tests by experiment rather than sequentially.

PWB Varying Stagnation Periods

After the faucets were identified and installed in the test rig, a test was conducted to determine the impact of stagnation periods as short as 30 minutes to as long as six hours. The six-hour period is the minimum stagnation duration required for LCR compliance sampling (USEPA, 1991). Water entered the faucets prior to the stagnation period and was collected out of the faucet at a flow rate of 1 L/min. This experiment was conducted at the beginning, middle, and end of testing at the PWB.

The results of the 1-L samples for the faucets are shown in Table C.4. As noted in Table C.1, the quality of the PWB tap water used during these experiment changed slightly over the course of the year. For the initial experiment, the water was the PWB's surface water source. The results showed no detectable lead in the samples from the leaded brass faucet selected to have the lowest lead release (Faucet 3) and the Envirobrass faucet (Faucet 4), though the results

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

from the other faucets were all less than 2 ⌠g/L. Lead release was generally found to increase between 0.5 hours and 3 hours, with no detectable change between 3 and 6 hours.

The second experiment conducted six months into the long-term testing showed lead release from the first 30 minutes had increased from <1 to 2 ⌠g/L to 4 to 5 ⌠g/L for all the faucets. For this experiment, the tap water used was also from PWB's surface water source. These results would appear to contradict the idea that lead release would be greatest at the beginning, when the wetted faucet metal was new and lacking passivation scales, and decrease with time as these scales develop. As will be discussed later for the long-term testing, lead release varied throughout the testing. The second major result was that lead release decreased to consistently <1 ⌠g/L after 3 and 6 hours of stagnation for this second experiment. Review of PWB laboratory records did not indicate anything during sample collection and testing that was in error; the researchers have no explanation for these trends.

Table C.4
Results from Testing at Varying Stagnation Periods

Sample time (hours of stagnation)	**Total Lead (⌠g/L) in 1-L sample for Faucet:**					
	1	**2**	**3**	**4**	**5**	**6**
First experiment – Day 0 of long-term testing (Oct. 4-5, 2005)						
0.5	<1	<1	<1	<1	2	<1
1	1	<1	<1	<1	<1	<1
3	2	1	<1	<1	1	1
6	2	1	<1	<1	1	*
Second experiment – Day 178 of long-term testing (May 23, 2006)						
0.5	4	4	5	5	4	4
1	4	4	4	5	5	5
3	5	5	<1	<1	<1	<1
6	<1	<1	<1	<1	<1	<1
Third experiment – Day 345 of long-term testing (Nov. 9, 2006)						
0.5	4	4	3	4	4	4
1	4	3	3	7	3	4
3	4	4	4	20	4	4
6	8	3	6	7	6	4

Note: * = sample was lost during collection

The third experiment was conducted when PWB had begun introducing groundwater to the tap water. As a result, the quality of the water used was slightly different than with the previous two experiments (see Table C.1). The third experiment essentially replicated the results from the second experiment for 0.5 hours and 1 hour of stagnation, followed by constant or increasing lead release for 3 hours and 6 hours of stagnation. Because of these results, the researchers believe that the results from the second experiment for the longer stagnation times may be anomalous. Despite the earlier classification of the faucets by high, mid-range, and low lead release, these results indicate lead release from the six faucets were essentially the same, with the exception of Faucet 4, the Envirobrass faucet. This particular faucet released more lead than the other faucets though the Envirobrass alloy was specifically developed to have very little lead. This release is especially evident in the 1-L sample for 3 hours of stagnation, where lead

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

was detected at 20 ⌠g/L, which is the highest result of all samples for this test. As will be noted later, the lead release from Faucet 4 is most likely the result of a valve component that was leaded brass.

PWB Long-term Simulated Residential Use

The second objective of the PWB testing was to analyze how lead levels changed over 12 months of simulated residential use. The same faucets from the varying stagnation time tests were used. The faucets were not cleaned, removed from the test rig, or otherwise disturbed between tests.

A timer controlled the frequency and duration of tap water flushing through the faucets for the test. Faucet flushing was a two-step procedure that occurred every morning and afternoon. The first step was to purge the water from the building plumbing and draw fresh tap water from the water main. This water was discharged to the sink. After a set time, the purging stopped and the fresh tap water was passed through each of the faucets simultaneously at a flow rate of 3 L/min for one hour.

Samples were collected after the six-hour stagnation period that started after the morning flushing. Sample collection was conducted frequently for the first weeks of the test to identify any initial rapid changes in lead release associated with the interior bare brass surfaces corroding in the presence of the tap water. Afterwards, the sampling frequency slowly decreased to once per month since the change to lead release was anticipated to slow once the brass surfaces had become fully passivated to the water. Table C.5 lists the sampling schedule used.

Each sample consisted of five sub-samples: four consecutive 60-mL sub-samples followed by one 760-mL sub-sample. The smaller initial sub-samples were to more accurately capture the lead profile from each faucet while the larger final sample was collected to calculate the lead concentration in an aggregate 1-L sample. The sampling results are shown in Figures C.5 through C.12 as concentrations.

Table C.5
Sampling Schedule for Long-Term Simulated Residential Use Test

Month	Collection Frequency	Collection Date
1	Twice weekly	Weeks 1 and 2: Monday and Thursday
1	Weekly	Weeks 3 and 4: Monday
2-3	Twice monthly	Weeks 2 and 4: Thursday
4-12	Monthly	Week 4: Thursday

The results show that there was an initial difference in the lead release from the identical faucets, with lead concentrations from Faucet 1 being nearly twice that of Faucet 2 in the first two sub-samples (0-60 mL and 61-120 mL). This difference decreased over time, and by approximately Day 145, was negligible. The results for Day 117 for Faucet 2 and Day 173 for both faucets found lead in both the fourth sub-sample (181-240 mL) and in the final 760 mL sub-sample. The lead release during these days was common to all faucets so these releases are hypothesized to be the result of some physical shock to the system that released particulates into the water.

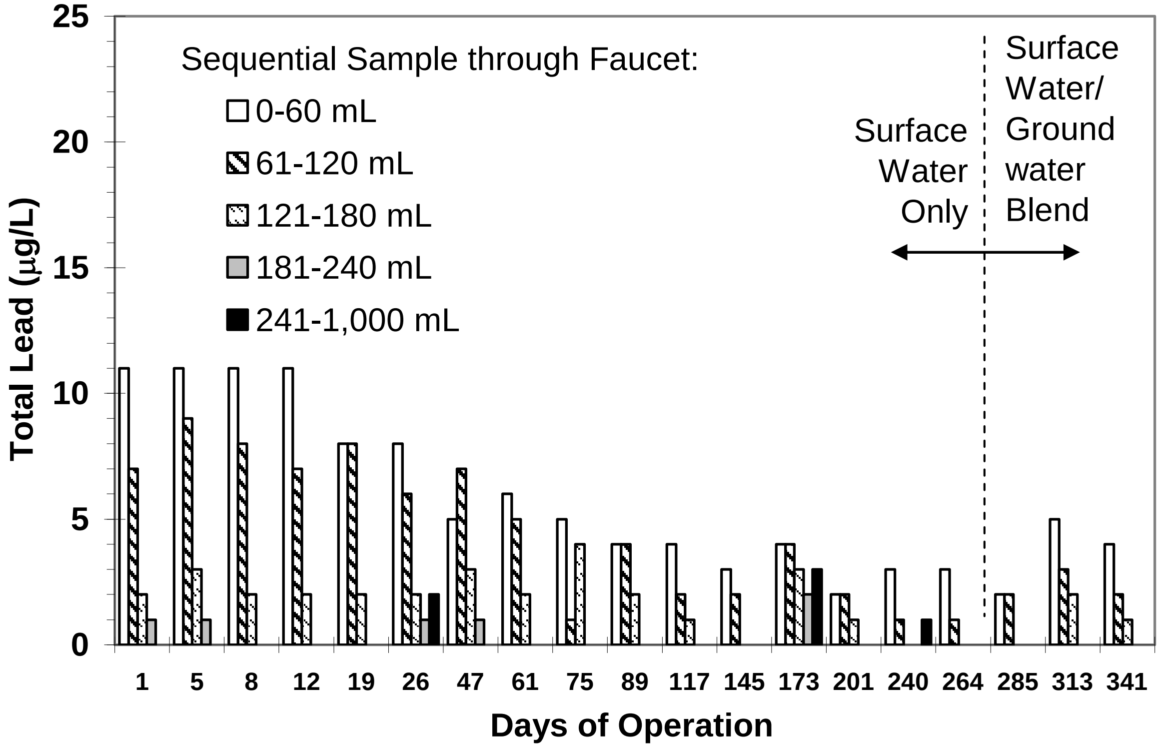


Figure C.5 Select total lead results from 6-hour stagnation times for Faucet 1 (highest detected lead). Internal volume = 201 mL.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

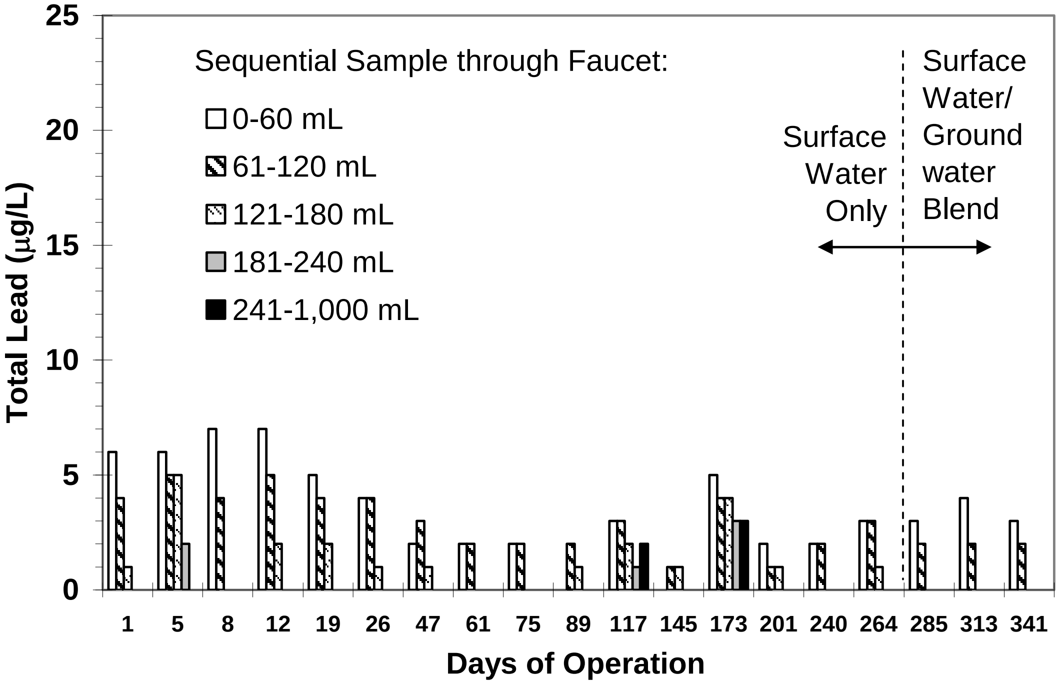


Figure C.6 Select total lead results from 6-hour stagnation times for Faucet 2 (duplicate of Faucet 1). Internal volume = 201 mL.

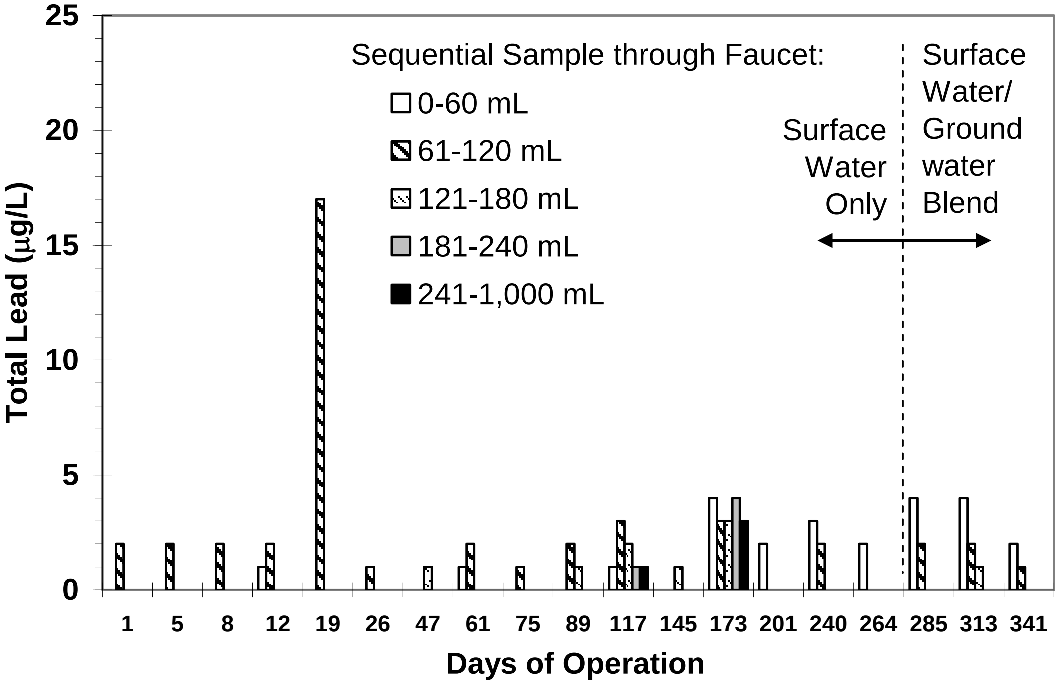


Figure C.7 Select total lead results from 6-hour stagnation times for Faucet 3 (lowest detected lead). Internal volume = 171 mL.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

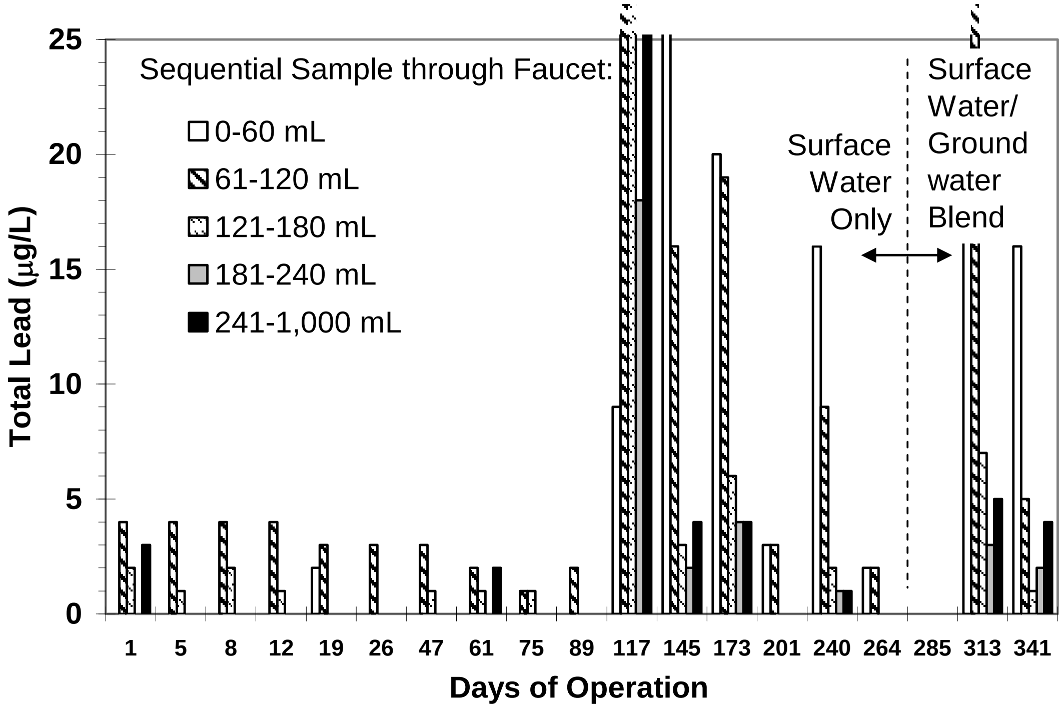


Figure C.8 Select total lead results from 6-hour stagnation times for Faucet 4 (Envirobrass). Internal volume = 134 mL.

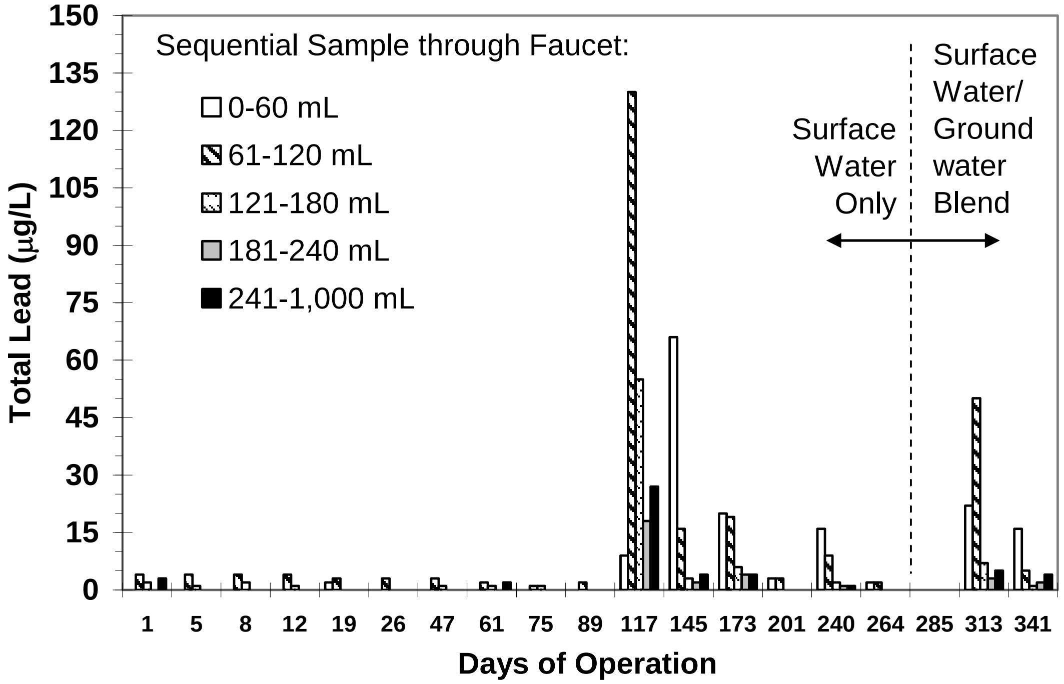


Figure C.9 Duplicate of (total lead results from 6-hour stagnation times for Faucet 4) with expanded y-scale.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

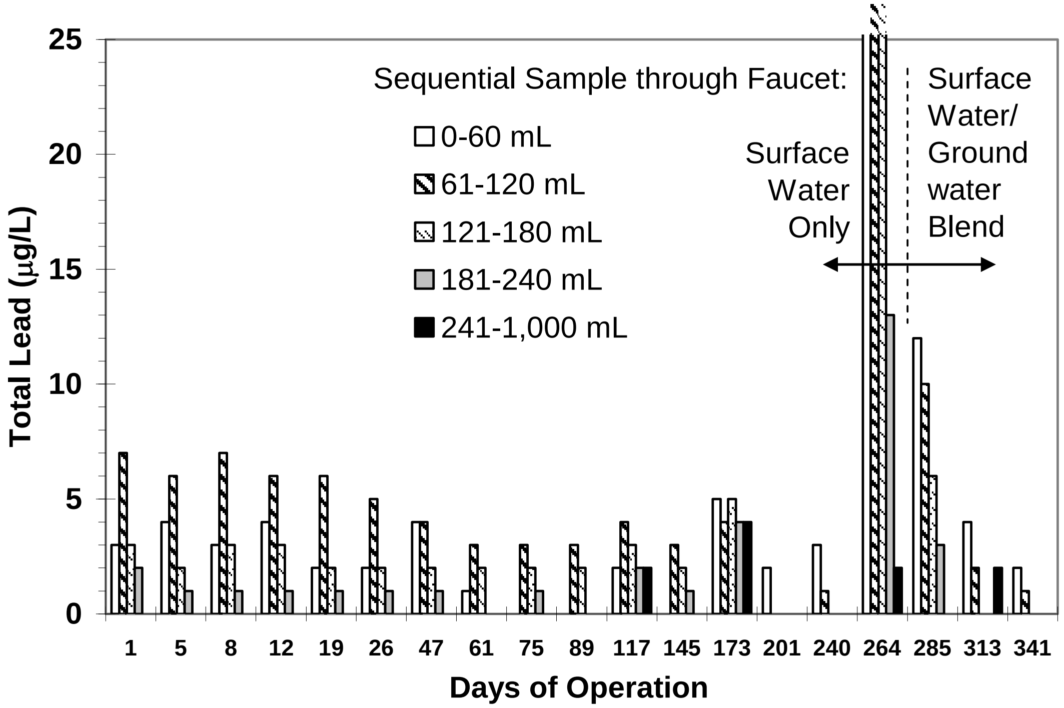


Figure C.10 Select lead results from 6-hour stagnation times for Faucet 5 (mid-range of detected lead). Internal volume = 162 mL.

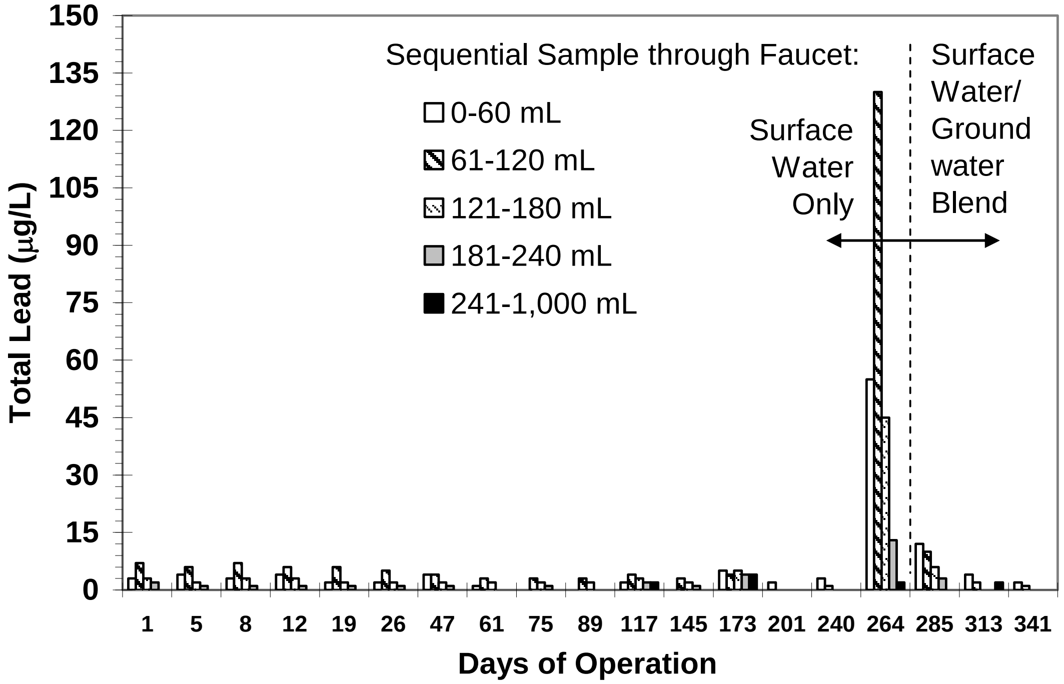


Figure C.11 Duplicate of (total lead results from 6-hour stagnation times for Faucet 5) with expanded y-scale.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

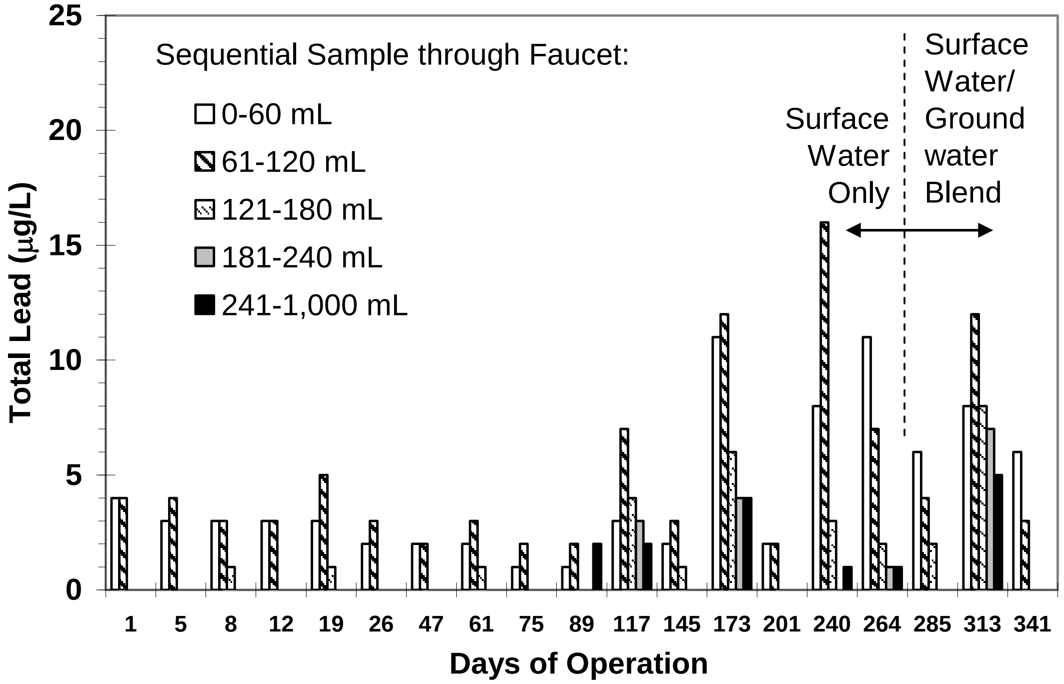


Figure C.12 Select total lead results from 6-hour stagnation times for Faucet 6 (California Proposition 65). Internal volume = 95 mL.

Unlike the first two faucets, where lead was consistently detected in the first 120 mL, Faucet 3 was found to have consistent lead release in only the second sample (61-120 mL of water through the faucet). Metallurgical analysis of a similar faucet (described later in this chapter) indicated that only a portion of the faucet body is actually leaded brass and that the spout is either composed of or lined with another metal. The metal composition analysis found that the spout contained <0.01 percent lead while the spout receiver and lower valve body was 1.83 percent lead.

The results for Faucet 4 (Envirobrass faucet) (shown in Figure C.8 and expanded in Figure C.9) generally found no detectable lead in the first 60 mL sub-sample for the first 89 days but up to 4 µg/L of lead was consistently detected in the second sub-sample (61-120 mL). The metallurgical analysis, described later in this chapter, found that though the majority of the wetted metal surfaces were either copper or Envirobrass with <0.1 percent lead content, the exterior of the mixing valve was leaded brass. As with the other faucets, Faucet 4 exhibited the high lead release on Days 117 and 173. However, the detected lead levels were among the highest of all the faucets tested. In addition, lead release after Day 117 was substantially higher than the release prior to Day 117, with >5 µg/L lead detected in nearly all of the first two sequential samples (0-60 mL and 61-120 mL). Lead was also detected in half of the other sequential samples during this period, which was actually sampling bulk water that had not been in stagnation contact with wetted metal. Faucet 4 was also tested for selenium because it is used in significant amounts to replace lead in the metal matrix. Selenium is a regulated element with a maximum contaminant level of 50 µg/L. However, every sub-sample analyzed found Se to be at concentrations of 0.6 µg/L or less.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Faucet 5 had sub-sample lead concentrations between those of Faucets 1 and 2. The other item to note about this faucet is that it was the only one that consistently had lead detected in the fourth sub-sample (181-240 mL) though the faucet's internal volume is only 162 mL. This faucet showed the elevated lead concentrations detected in Days 117 and 173 as well as in Days 264 and 285. Since the results for the Day 264, and to a lesser extent Day 285, were among the highest detected without a correlation with other faucets, the lead release is hypothesized to be due to the release of particulate material from the faucet.

Faucet 6 was found to have lead leaching similar to that of Faucet 2 for the first 201 days of operation, with lead concentrations between 1 and 5 µg/L for the first 120 mL of water through the faucet. After Day 201, the faucet was determined to be releasing lead up to 16 µg/L in the first 120 mL, with additional lead found in the third (121-180 mL) and fourth (181-240 mL) sub-samples.

Figures C.13 and C.14 shows the same results but based on the total lead mass, as opposed to concentration, released through the aggregated 1-L of water through the faucets. Excluding the previous common elevated concentrations on Days 117 and 173, Faucets 1, 2, and 3 were found to have lead release in an aggregate 1-L to be ≤3 µg/L and generally <1 µg/L. Faucet 4, the Envirobrass faucet, had the highest aggregate 1-L lead results. Faucets 5 and 6 had aggregate levels of lead above Faucets 1, 2, and 3 but less than Faucet 4.

Finally, the change in the PWB tap water from being solely surface water for Days 1 through 264 to a blend of ground and surface waters afterwards did not result in quantifiable differences in the lead release for any of the faucets. While shifts in water chemistry are known to result in corresponding changes in metals corrosion, such differences for the PWB faucets are masked by 1) the variability of the results and 2) the fact that only three rounds of samples were collected during this period.

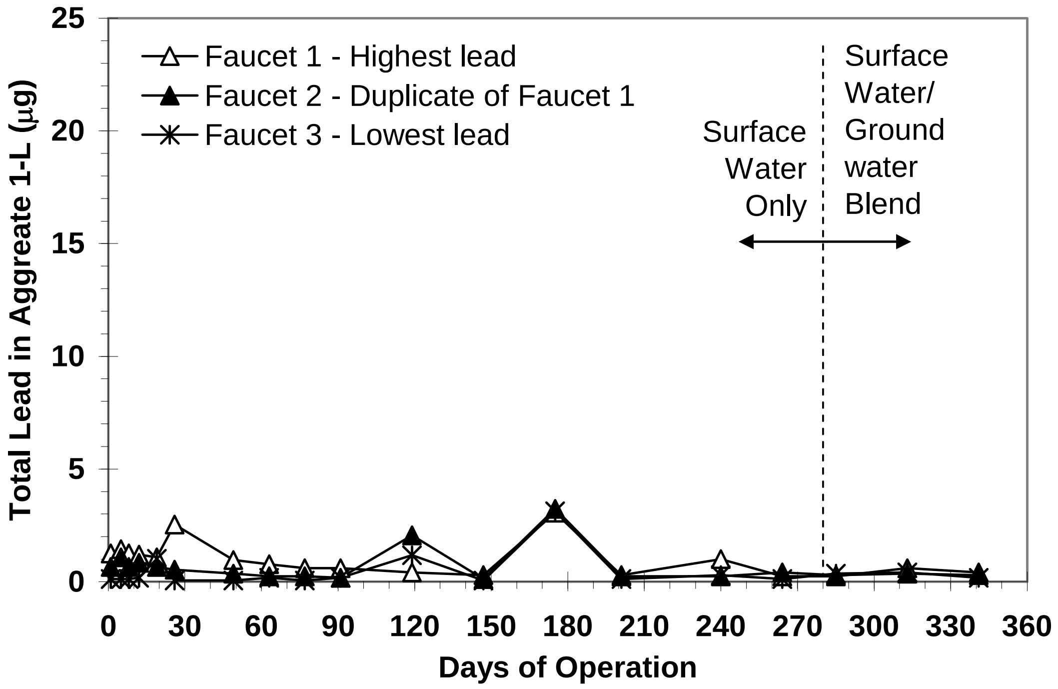


Figure C.13 Total lead mass in aggregate 1-L samples for Faucets 1, 2, and 3 over time.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

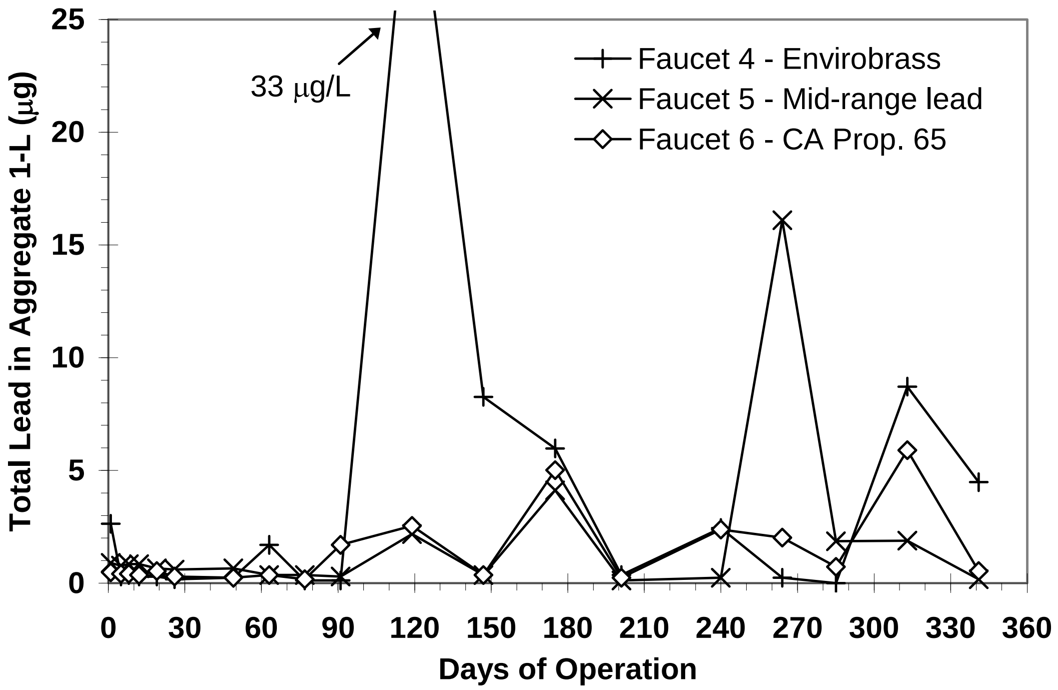


Figure C.14 Total lead mass in aggregate 1-L samples for Faucets 4, 5, and 6 over time. (Transition from surface water and surface water/groundwater blend at approximately Day 280 not shown for clarity).

PWB Impact of Sampling Flow Rate

The previous experiments were conducted by sampling the stagnated water samples at a low flow rate of 1 L/min. The third PWB experiment was to determine if different flow rates had an impact on the lead results. Specifically, the experiments were conducted to determine if the additional turbulence induced by higher flow rates result in additional lead release from the faucets. This experiment consisted of collecting a single 1-L 6-hour stagnation sample at the following flow rates: 1-L/min, 2-L/min, 4-L/min, and the maximum flow rate (the flow rate obtained by fully opening the cold water valve). This maximum flow rate was ~8.3-L/min for all the faucets. This experiment was conducted once in the middle (Day 188) and the end of the long-term stagnation testing (Day 353). The testing during the middle was conducted when PWB was using solely surface water as the tap water source while testing at the end was during the period where the tap water was a blend of surface water and groundwater.

Figures C.15 through C.17 show the results of this experiment. The results for the 1 L/min sampling at Day 188, at 1 µg/L or less, were comparable to the Day 210 calculated aggregate 1-L results shown in Figure C.13 and C.14 (as noted earlier, Day 173 results were believed to be anomalous). Lead concentrations in the 1-L sample collected at 1-L/min at Day 353 were <1 µg/L for all faucets except Faucet 4 (Envirobrass), which lead release was found to be at 7 µg/L. In comparison, the calculated lead release in a 1-L sample for Day 341 for Faucet 4 was 5 µg/L and <1 µg/L for the other faucets. Aside from the results of Faucet 4, the lead release is too low to indicate if there were any consistent changes in lead release from the faucets between Days 188 and 353.

There was a general trend in that increasing the sampling flow rate up to 4 L/min resulted in higher lead concentrations in the 1-L sample, with the greatest increase found for Faucet 4. Lead release then consistently decreased during sampling at the maximum flow rate. This behavior is hypothesized is to be functions of both water velocity-induced turbulence and water transit time through the faucet. As the flow rates increased, velocity-induced turbulence becomes stronger and the boundary interface water between the bulk water and wetted metal mixes more into the bulk water, which then exits out the faucet and into the collected sample. At between 4-L/min and the ~8.3-L/min flow rate, the water velocity increased to the point more of the bulk water passes through the faucet without mixing with the boundary water. As a result, the higher flow rate results actually diluting the amount of lead concentrations in captured samples.

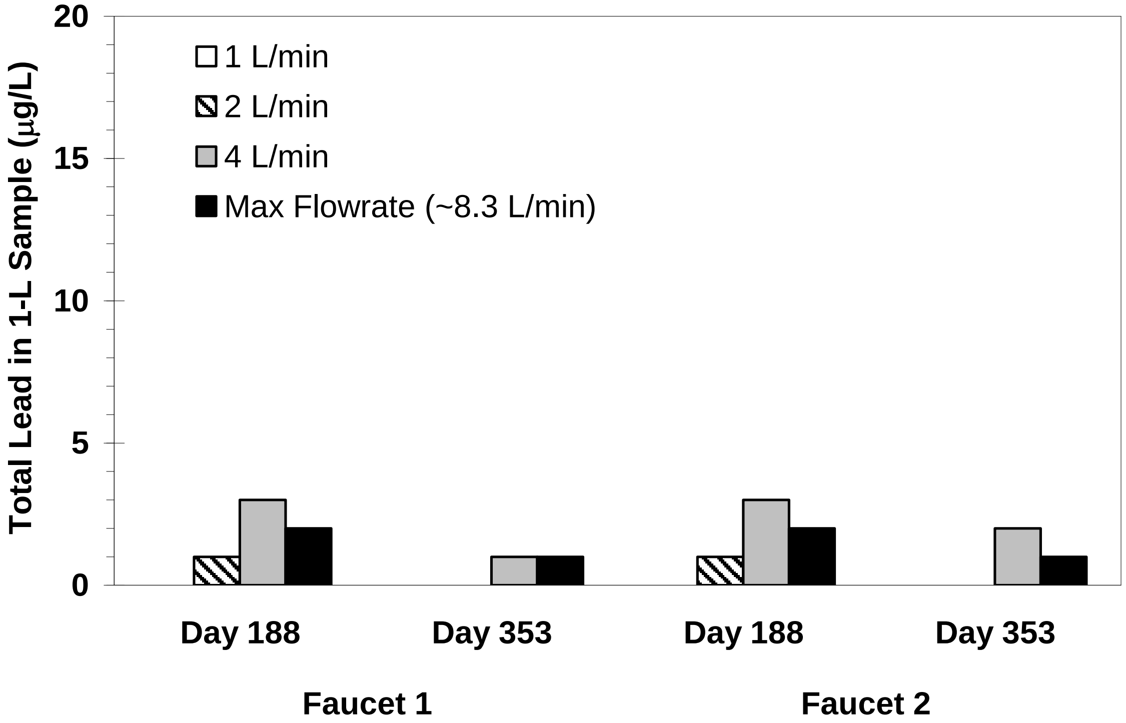


Figure C.15 Total lead in 1-L samples for Faucets 1 and 2 as function of sampling flow rate.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

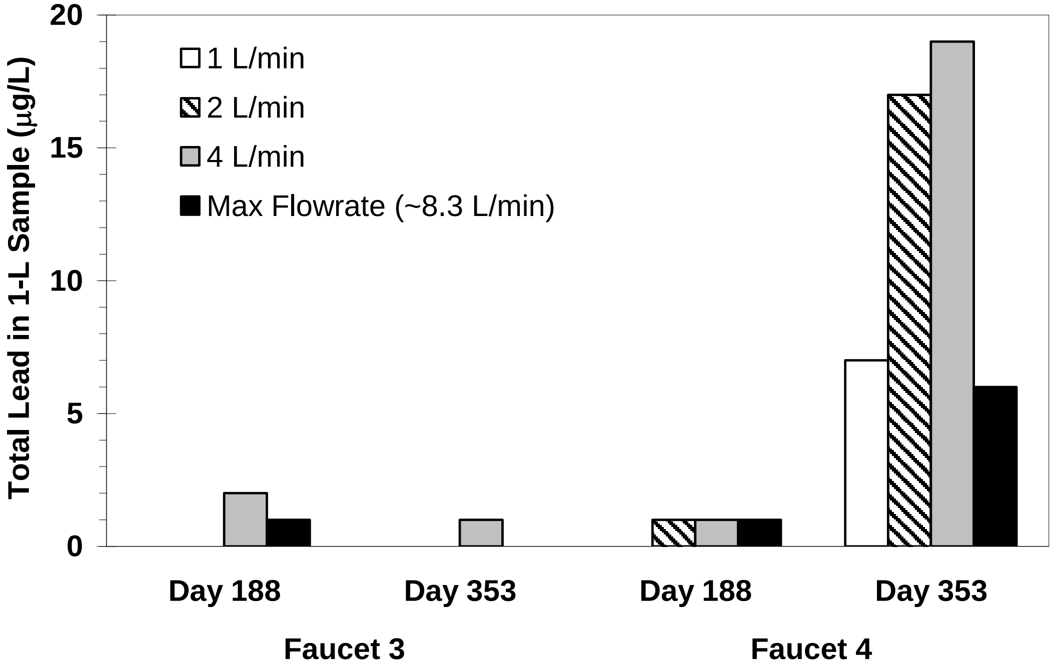


Figure C.16 Total lead in 1-L samples for Faucets 3 and 4 as function of sampling flow rate.

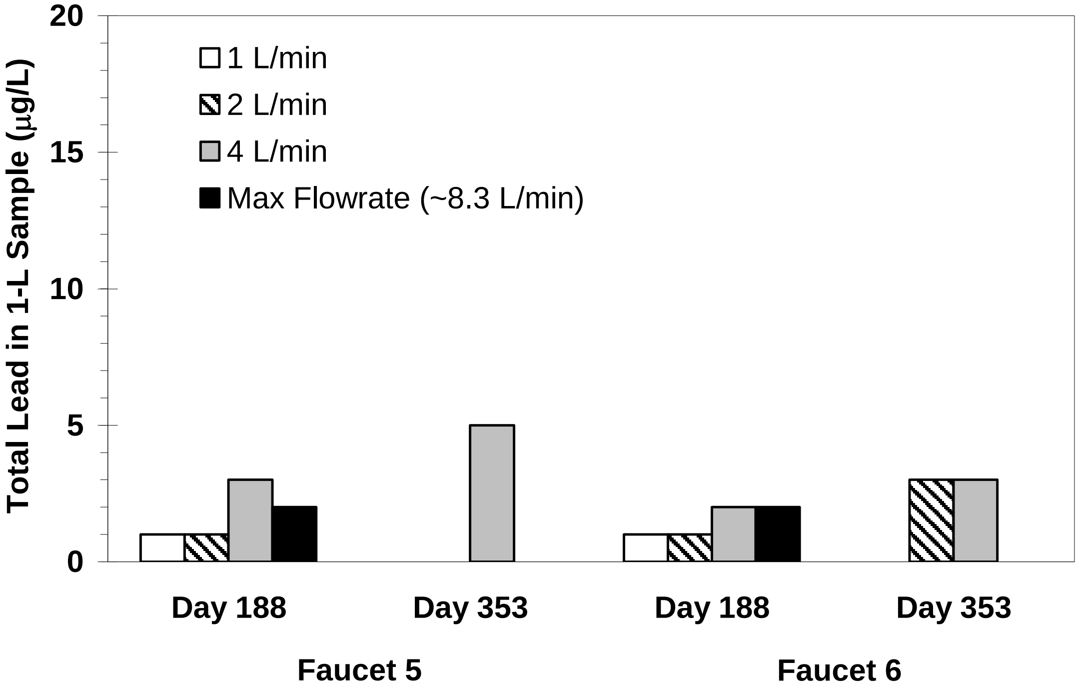


Figure C.17 Total lead in 1-L samples for Faucets 5 and 6 as function of sampling flow rate.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Metallurgical Analysis

The results of the metallurgical analysis of duplicate faucets to those used at the PWB are listed in Appendix D and summarized in Table C.6. The analysis found that the four leaded brass faucets (Faucets 1 and 2 [duplicates], 3, 5, and 6) generally consisted of the following parts:

- A leaded brass cold water fitting.
- A cold water tube of copper or plastic with stainless steel exterior braiding.
- A leaded brass valve body and spout receiver. The valve body is either one or two pieces.
- A non-leaded brass spout.

Faucet 4 replaced the leaded brass components with the Envirobrass alloy. The other components, cold water tube and spout, were the same general materials as to other faucets tested.

The results found that the lead concentration, on a weight/weight basis, did not correspond with the lead release initially identified by the PWB testing shown in Figure C.3 or with the subsequent twelve months of long-term testing. For example, the highest lead faucets (Faucets 1 and 2) had roughly the same amount of lead in the faucet components as Faucet 3, the lowest lead release faucet). Faucets 5 and 6 had the most lead in the faucet components though the lead release found during the long-term testing did not necessarily correspond to the highest lead detected during the sequential samples. In addition, the testing confirmed that the Faucet 4 contained the least overall amount of lead of all faucets though it had the highest lead release. However, as will be discussed later, the valve within valve body was manufactured with a leaded brass casing.

Table C.6
Metal composition of PWB faucet duplicates

	Faucet				
Faucet Component	**1 and 2 Highest lead**	**3 Lowest lead**	**4 Envirobrass**	**5 Mid-range lead**	**6 CA. Prop. 65**
Cold water fitting	B(2.0)	B(2.7)	E	B(3.4)	B(3.4)
Cold water tube	P-SS	P-SS	C	C	C
Valve body	B(1.9)	B(1.9)	E/B (~3.0)	B(2.8)	B(3.4)
Spout receiver	B(3.0)	B(1.8)	E	B(2.5)	B(3.3)
Spout	B(NL)	B(NL)	B(NL)	B(NL)	B(NL)

Legend:
B(“x”) = brass (with lead): 57 – 59% copper, 36 – 39% zinc, <0.01% bismuth; “x” designates lead concentration on weight/weight basis.
B(NL) = brass (no lead): 64 – 69% copper, <0.1% lead, 31 – 36% zinc, <0.01% bismuth
E = Envirobrass: 87 – 90% copper, <0.1% lead, 3.8 – 4.8% zinc, 1.6 – 1.8% bismuth
P-SS = plastic tube with stainless steel exterior braiding
C = copper

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

ANSI/NSF Standard 61, Section 9 Testing

The results of the ANSI/NSF Standard 61, Section 9 testing of the duplicate, unused PWB faucets are tabulated in Table C.7. In addition, the results of the 19-day ANSI/NSF Standard 61, Section 9 testing are plotted against the PWB testing results in Figures C.18 through C.22. The duplicate to Faucets 1 and 2, the model identified by PWB has having the highest lead release after a 24-hour stagnation period, was also the duplicate faucet with the highest statistical Q value at 18 ⌠g/L. This value also exceeds the NSF Q limit of 11 ⌠g/L required to obtain ANSI/NSF 61 certification. However, the statistical Q value is developed using the results from three faucets. Figure C.18 shows that the NSF testing found that one of the faucets (NSF designation D1) released lead at nearly an order of magnitude greater than NSF Faucet D2, which in turn released twice the amount of lead than NSF Faucet D3. As with the PWB testing, these differences in the NSF testing emphasize the variability of lead release from a specific faucet model. The result is that though the NSF testing found that the PWB-identified highest lead release faucet also had the highest Q value, the correlation is potentially skewed by the large variability in both the NSF and PWB test results. (The NSF Q value results cannot be directly compared to the first 19 days of testing at the PWB due to the differing sampling methodologies used. The NSF testing collected and analyzed single volumes of water collected from fill-and-draw operation while testing at PWB involved the collection of four sequential samples that did not exactly correspond to the internal wetted faucet volume. In addition, the Q statistic takes into account the variability in the sample set.)

Table C.7
ANSI/NSF Standard 61, Section 9 results for duplicates of PWB faucets

	Concentration (µg/L) for:				
Faucet	**Lead Q**[a]	**Bismuth**[b]	**Copper**[b]	**Nickel**[b]	**Zinc**[b]
1 and 2 – Highest lead	18	<0.1	68	11	91
3 – Lowest lead	11	<0.1	66	2	160
4 – Envirobrass	11[c]	0.5	120	14	84
5 – Mid-range lead	2.7	<0.1	87	2.9	71
6 – CA. Prop. 65	1.7	<0.1	53	0.3	58

Notes:

a. NSF Statistical Q value for lead
b. Measurement at final day of testing
c. Based on two faucets instead of three

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

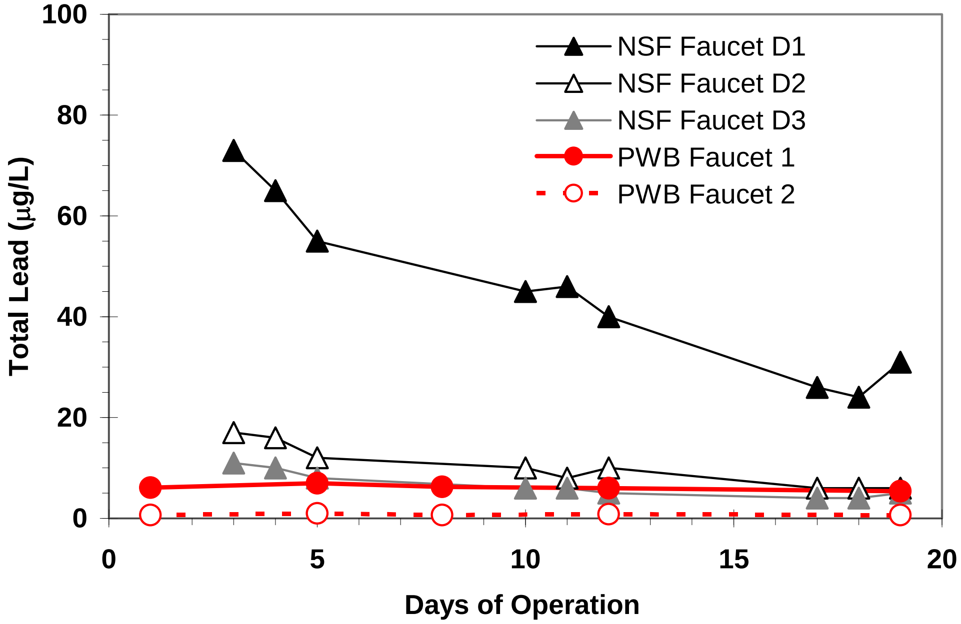


Figure C.18 ANSI/NSF Standard 61, Section 9 results for PWB-identified highest lead release faucet (PWB Faucets 1 and 2).

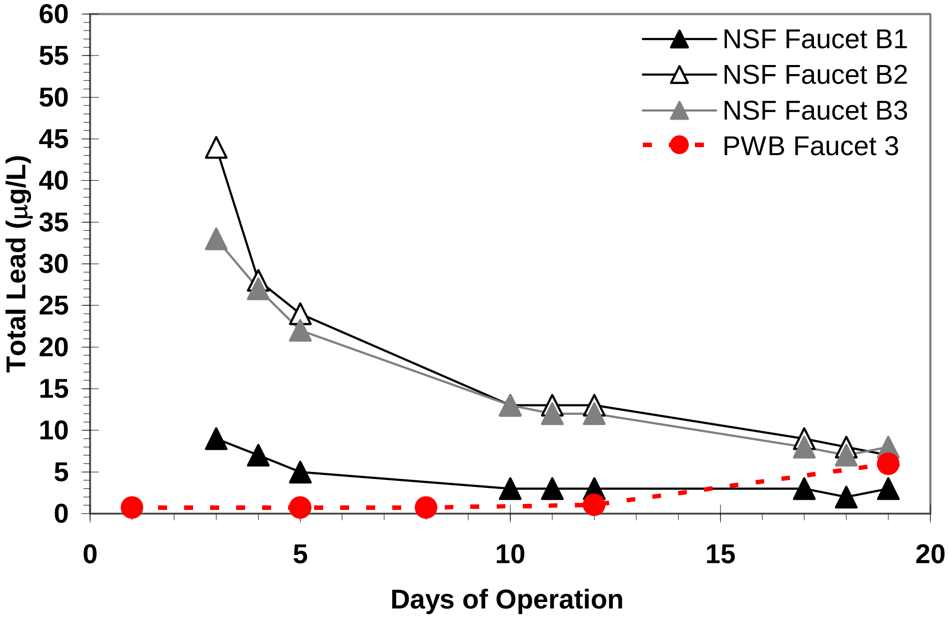


Figure C.19 ANSI/NSF Standard 61, Section 9 results for PWB-identified lowest lead release faucet (PWB Faucet 3).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

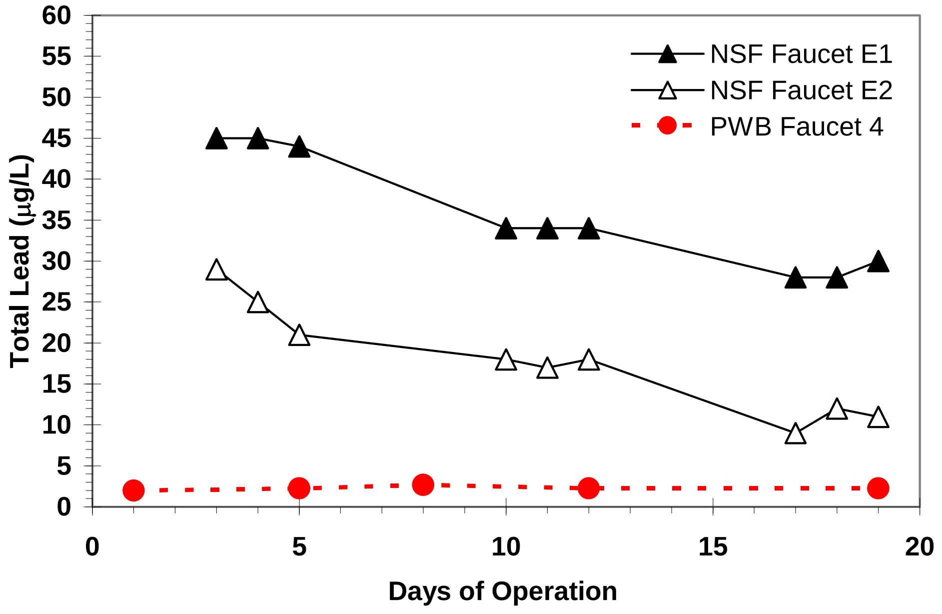


Figure C.20 ANSI/NSF Standard 61, Section 9 results for Envirobrass faucet (PWB Faucet 4).

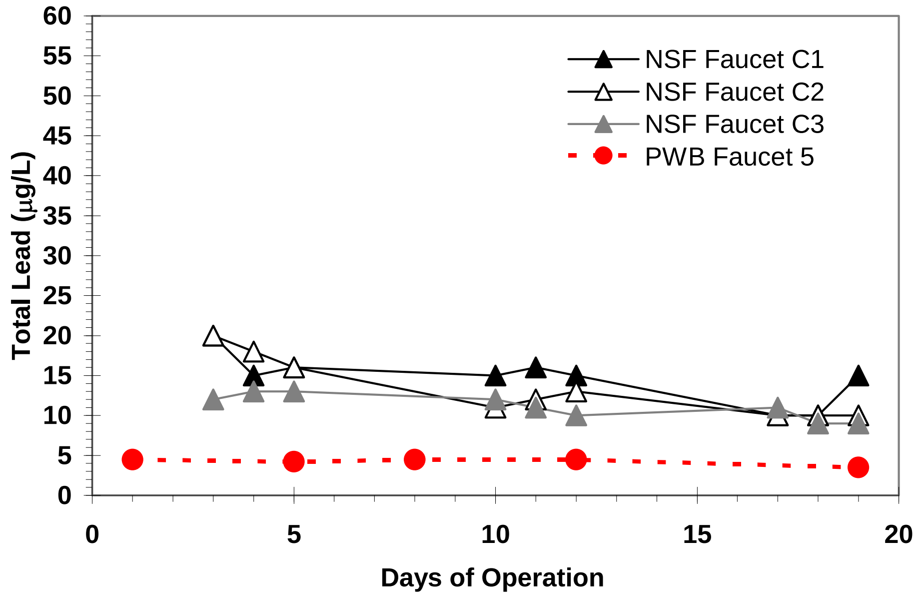


Figure C.21 ANSI/NSF Standard 61, Section 9 results for PWB-identified faucet with lead release in the middle of the range of those tested (PWB Faucet 5).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

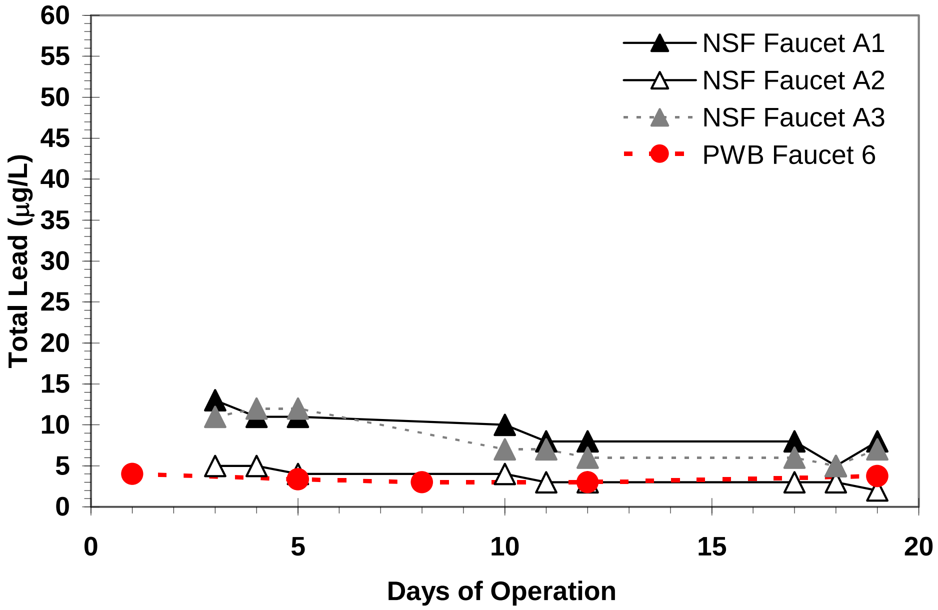


Figure C.22 ANSI/NSF Standard 61, Section 9 results for California Proposition 65 faucet (PWB Faucet 6).

Similarly, the faucet selected at PWB as the mid-range and lowest lead release did not have Q values that corresponded to their identification label. The lowest lead release faucet was found in the NSF analysis to have a Q value at the ASNI/NSF Standard 61, Section 9 certification limit, though the prior PWB testing indicated that this particular faucet model released the least amount of lead in every experiment conducted. In this case again, the faucets analyzed for the NSF analysis showed differing lead leaching characteristics, with one faucet having substantially less lead release than the other two (see Figure C.19). In comparison, the NSF-analyzed triplicates of the mid-range faucets (PWB Faucet 5) and the California Proposition 65 faucets (Faucet 6) were found to have very similar lead leaching throughout the ANSI/NSF Standard 61, Section 9 testing protocol (see Figures C.21 and C.22, respectively).

The Envirobrass faucet (PWB Faucet 4) was also found during the NSF testing to have a Q value for lead at the certification limit, which again belies the claim that using the very low-lead Envirobrass alloy corresponds to very-low lead release. Of the major brass elements, the Envirobrass faucet was found to release the most copper and nickel as well. Bismuth was found detected from only this faucet, though this result was expected as the prior metallurgical analysis determined that only this faucet contained the element.

In general, the Q value results were higher in all cases than the rig results for the first 3 months of the simulation test, and higher than over 90% of the values seen over the entire test period. Some of the faucet rig results that did exceed the Q value results in the later portions of the study may be due to particulate lead release.

Faucet Aerator Metals Accumulation Analysis

After the conclusion of the PWB long-term testing, the aerators were removed for analysis of accumulated metals on the interior of the aerator screens. Figure C.23 shows the accumulation the aerators. Each aerator was found to have retained a red material over the

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

course of testing to completely cover the aerator. The accumulations formed despite a deliberate flushing program designed eliminate this issue. The retained material in the aerators for Faucets 1, 2, and 4 were also found to contain a white mineral; while not analyzed, the mineral is suspected to be calcite ($CaCO_3$). Finally, the Faucet 4 aerator was found to have retained what appeared to be a sliver of plastic or Teflon tape.

Table C.8 shows the results of the metals analysis. The reddish material was found to a ferric oxide/hydroxide mixture that is most likely from older galvanized premise piping within the PWB Water Quality Laboratory. An interesting result is that lead was below the detection limit for each of the six aerators, as was copper, the major element in brass. This conclusion is interesting because lead was found to have been released from several of the faucets at high concentrations. There are three potential conclusions that could be drawn from these results.

1. All lead released during the long-term testing was as dissolved lead, including each of the high spikes of lead occasionally detected.
2. The aerator and retained ferric layer does capture lead particles but these particles subsequently dissolve and are regularly flushed from the faucet.
3. The interstitial spacing in both the aerator and formed iron layer was too large to trap any released particles.

The first hypothesis is not likely because of the assumption that all lead release is dissolved. As noted in other testing conducted for this report, most instances of high lead release was due to the particulate lead. The second hypothesis assumes complete dissolution occurred for each faucet, which would account for the lack of lead and copper in the accumulated metals. However, particulate dissolution would have to been relatively quick and complete. The third hypothesis may be the most likely since it would simply account for the lack of accumulated metals without requiring a chemical dissolution process. For this hypothesis, a faucet aerator would normally not act as a trap for particulate lead.

Table C.8

Analysis of materials accumulated in Portland Water Bureau aerators after long-term testing

	Elemental composition (% abundance by mass)					
Element	1	2	3	4	5	6
Lead	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Oxygen	13.7 ± 5.9	30.2 ± 13.4	26.5 ± 11.2	19.2 ± 7.9	26.8 ± 8.4	21.5 ± 7.9
Aluminum	5.3 ± 2.3	15.4 ± 24.7	6.6 ± 6.8	18.4 ± 25.2	2.8 ± 0.7	9.9 ± 14.5
Silicon	14.2 ± 4.5	9.9 ± 6.6	9.3 ± 3.3	11.1 ± 5.9	8.6 ± 1.2	12.3 ± 2.2
Calcium	2.9 ± 1.4	2.3 ± 1.7	1.1 ± 0.4	2.4 ± 0.9	1.5 ± 0.3	2.2 ± 0.4
Manganese	3.3 ± 1.0	2.2 ± 1.4	3.1 ± 1.9	5.3 ± 2.9	7.0 ± 0.9	3.9 ± 1.1
Iron	45.5 ± 6.3	24.6 ± 17.0	23.8 ± 8.1	29.2 ± 10.0	36.0 ± 5.6	36.6 ± 12.6
Nickel	1.4 ± 0.8	<1.0	<1.0	<1.0	<1.0	<1.0
Zinc	<1.0	<1.0	17.0 ± 4.9	<1.0	4.4 ± 0.7	<1.0

Note: Sodium, magnesium, phosphorus, sulfur, chloride, potassium, copper, and tin were also analyzed and found at <1.0% abundance by mass.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Faucet 1

Faucet 4

Faucet 2

Faucet 5

Faucet 3

Faucet 6

Figure C.23 Aerators removed from faucets used for long-term testing at the Portland Water Bureau.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scale Analyses

Six faucets from the Portland faucet rig experiment were tested for scale development and for effects of leaching on metal compositions. Two of the units tested were replicates – Faucets 1 and 2. Metal composition of the faucets before being placed in the rig was determined by analysis of duplicate samples by the Copper Development Association (Table C.9).

Table C.9
Metal contents of faucets used in scale analysis

Unit	Vol., ml	Average Pb %	Average Cu %	Average Zn %	Zn/Cu
Faucet 1	201	2.43	57.7	38.9	0.67
Faucet 2	201	2.43	57.7	38.9	0.67
Faucet 3	171	2.13	57.6	39.1	0.68
Faucet 4	134	0.080	91.5	4.15	0.047
Faucet 5	162	2.35	57.8	38.0	0.66
Faucet 6	95	2.87	57.7	37.2	0.65

Averages calculated from analyses of lower and upper valve body plus spout receiver, excluding spout

ANSI/NSF 61 Testing

Additional duplicates of the faucets used in the scale study were tested using the NSF 61 protocol. Faucets 1 and 2 exceeded the Pb limit of 11 ⌠g/L. Amounts of Cu and Zn are also available from this test. The high ratios of Zn to Cu in the leachate compared to the ratios in the metal indicate strong dezincification of the brass in these faucets in the test procedure (Table C.10).

Table C.10
Metal release results from NSF 61 testing

Unit	Vol., ml	NSF 61 Pb - Q µg/L	NSF 61 Cu µg/L	NSF 61 Zn µg/L	Zn/Cu	$Zn/Cu_{leachate}/$ Zn/Cu_{solid}
Faucet 1	201	18	11	91	8.3	12
Faucet 2	201	18	11	91	8.3	12
Faucet 3	171	11	2	160	80	118
Faucet 4	134	11	14	84	6.0	128
Faucet 5	162	2.7	2.9	71	24	36
Faucet 6	95	1.7	.3	58	190	292

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Water chemistry

The following water quality parameters were measured for each faucet during the PWB faucet rig experiment: alkalinity, pH, and temperature. Other parameters were available for the source water from the PWB annual water quality reports. Combining these data sources, a series of PHREEQC model experiments were run for each faucet for a one-liter draw and for the first 100 ml. Table C.11 lists the results of this modeling

The only Pb mineral calculated to be at equilibrium with the water was the phosphate, pyromorphite. The mineral next closest to saturation was the carbonate, cerussite, but it is always somewhat undersaturated (negative saturation index).

Note in Table C.11 the variable amounts of Pb released and also that the replicate Faucets 1 and 2 released quite different Pb amounts.

Scale Development

None of the faucets showed extensive scale development. That is, passivating scales did not form over the one-year period of the experiment, although in some cases small patches of scale did form. Instead, the dominant process is the formation of a Zn-depleted layer on the internal surfaces of the faucets. This process is most easily seen with Faucets 1 and 2 (Figures C.24 and C.25).

Table C.11
Summary of results of PHREEQC modeling for Portland faucet rig

		Cerussite	**Pyromorphite**		**Cerussite**	**Pyromorphite**
Faucet	**1st liter Pb, µg/L**	**S.I.**	**S.I.**	**1^{st} 100 ml Pb, µg/L**	**S.I.**	**S.I.**
1	1.03	-1.85	1.83	6.03	-1.10	5.59
2	0.75	-2.01	1.06	3.83	-1.30	4.60
3	0.50	-2.18	0.18	2.19	-1.54	3.39
4	3.65	-1.32	4.50	13.14	-0.76	7.28
5	1.82	-1.62	2.99	9.90	-0.89	6.66
6	1.36	-1.75	2.35	5.62	-1.13	5.44

Pb concentrations are averages of 18 sequential draws over one year of operation of faucets

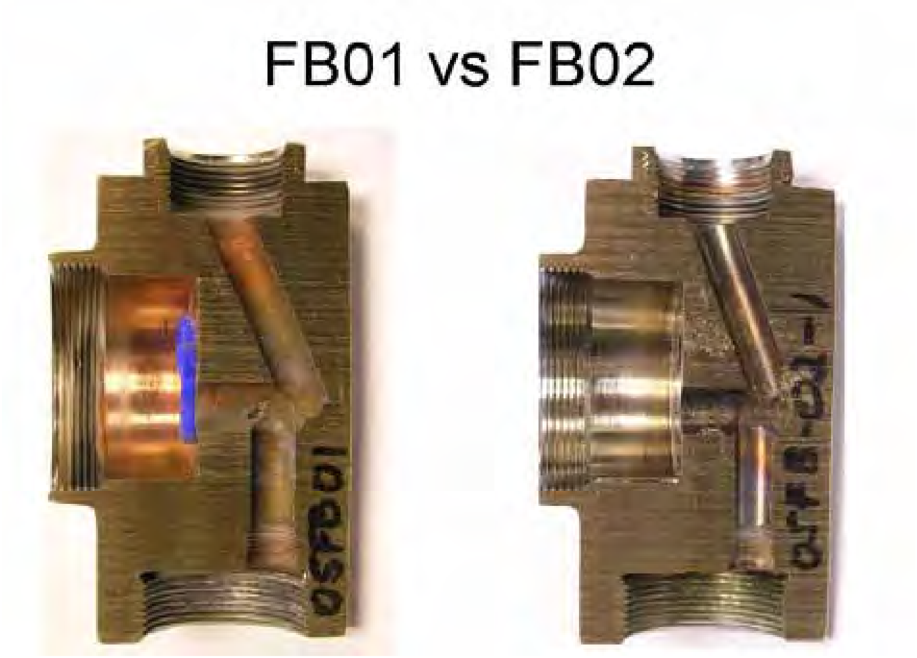


Figure C.24 Cut sections through the valve body for Faucets 1 and 2. Although identical designs from the same manufacturer, behavior is quite different. FB01 has a well-developed copper color, indicating dezincification, whereas FB02 largely retained its original yellow brass color.

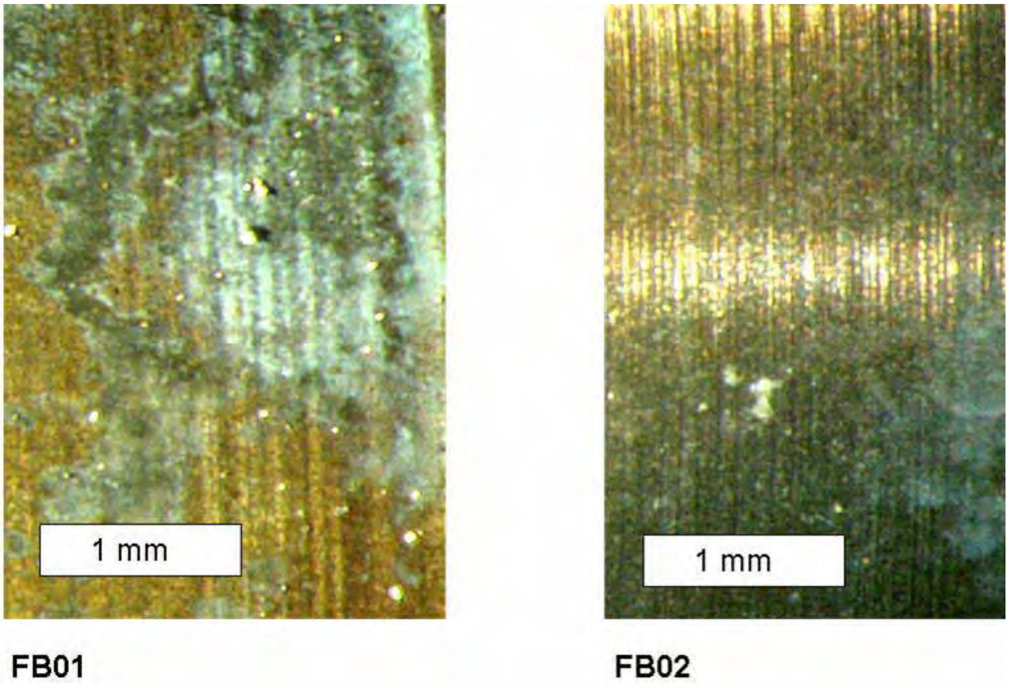


Figure C.25 Photomicrographs of the valve body for Faucets 1 and 2 show spotty scales in both, but heavier coverage in FB01.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Dezincification of the brass can be imaged using the back-scattered electron technique. In this procedure, the intensity of the electron image increases as the atomic number of the target atom increases. In the scans below (Figures C.26 and C.27), Pb-rich regions are very bright, normal brass is gray, and Zn-depleted brass is dark gray. Note that the Cu and Zn form a solution, but that the Pb component remains as isolated distinct bodies a few tenths of a micron across.

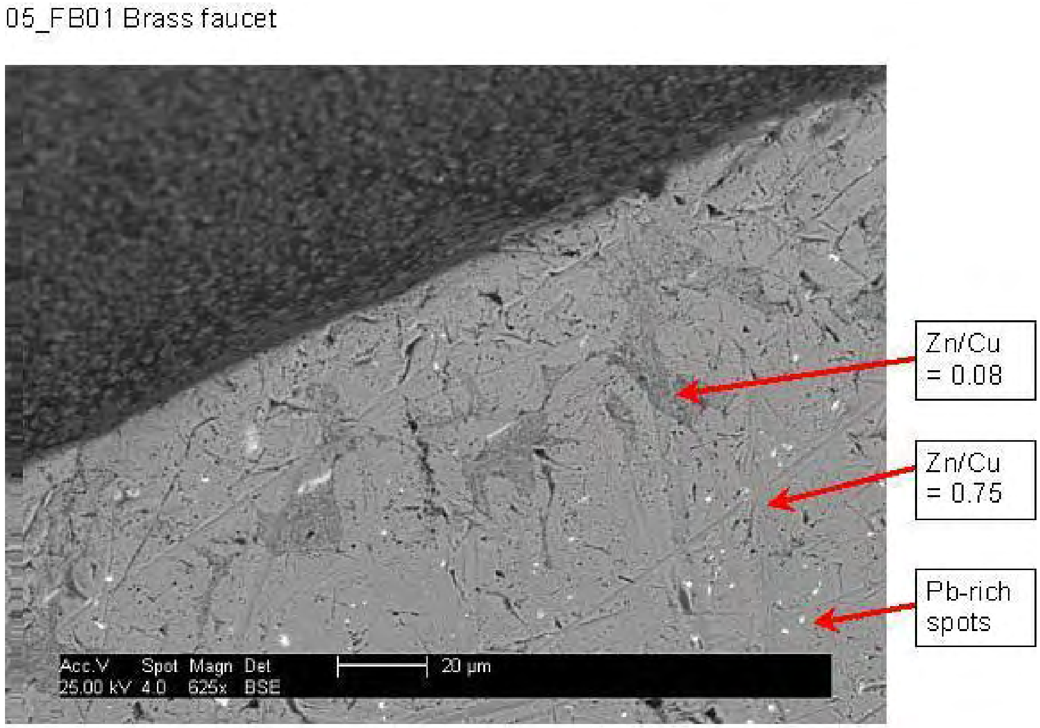


Figure C.26 Back-scatter image of the edge of the brass along an interior surface of Faucet 1. A zone a few microns thick at the surface has been depleted in Zn, and porosity (the black areas) has developed.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

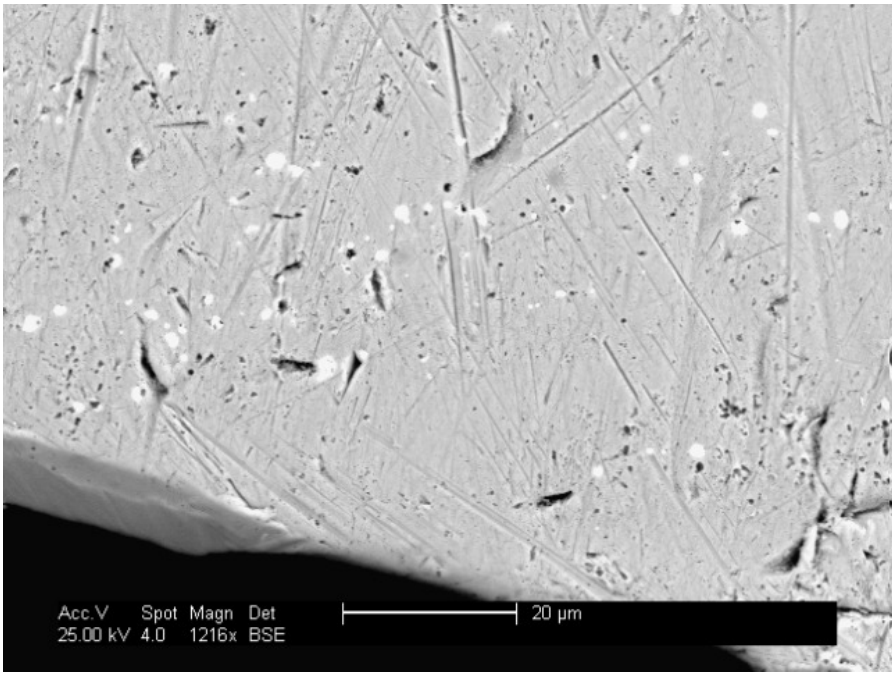


Figure C.27 Back-scatter image of the edge of the brass in Faucet 2. No Zn-depleted areas are visible.

The brass in the two versions of this faucet used in the rig was in fact slightly different. Energy dispersive analysis (EDS) in the SEM showed Zn/Cu to be 0.75 in Faucet 1, whereas in Faucet 2 it was 0.92. Thus Faucet 2 has higher Zn than its twin, showing the range of variability in manufacturing. Furthermore, it would appear that the higher Zn faucet is *less* susceptible to dezincification.

Dezincification was also seen extensively developed in Faucet 4. Back-scatter imaging of the spout from this faucet shows severe dezincification that underlies organic-rich crusts on the brass, consistent with a microbial role in the brass corrosion (Figures C.28, C.29, and C.30). See Valcarce et al. (2005) for a discussion of microbial effects in brass corrosion.

Faucet 4 also showed the heaviest scale buildup on the valve body. This scale comprises mostly copper carbonates, but many areas show a surprisingly high zinc concentration, which appears to be in the form of a zinc oxide mineral.

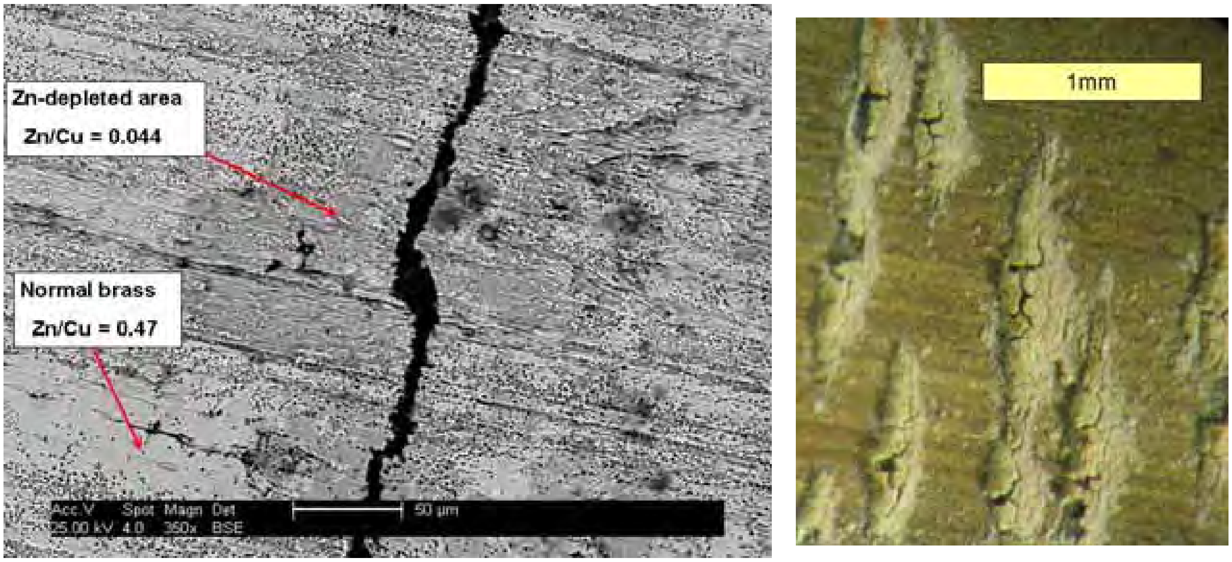


Figure C.28 Back-scattered electron image of spout. Tension cracks from shaping the spout have become localized areas of corrosion. There is a marked dezincification along all of these cracks -- bright areas are zinc-rich, normal brass; gray areas are zinc-depleted. When received, these cracks were covered by a fragile, organic-rich accumulation, likely microbial in origin, shown on the right.

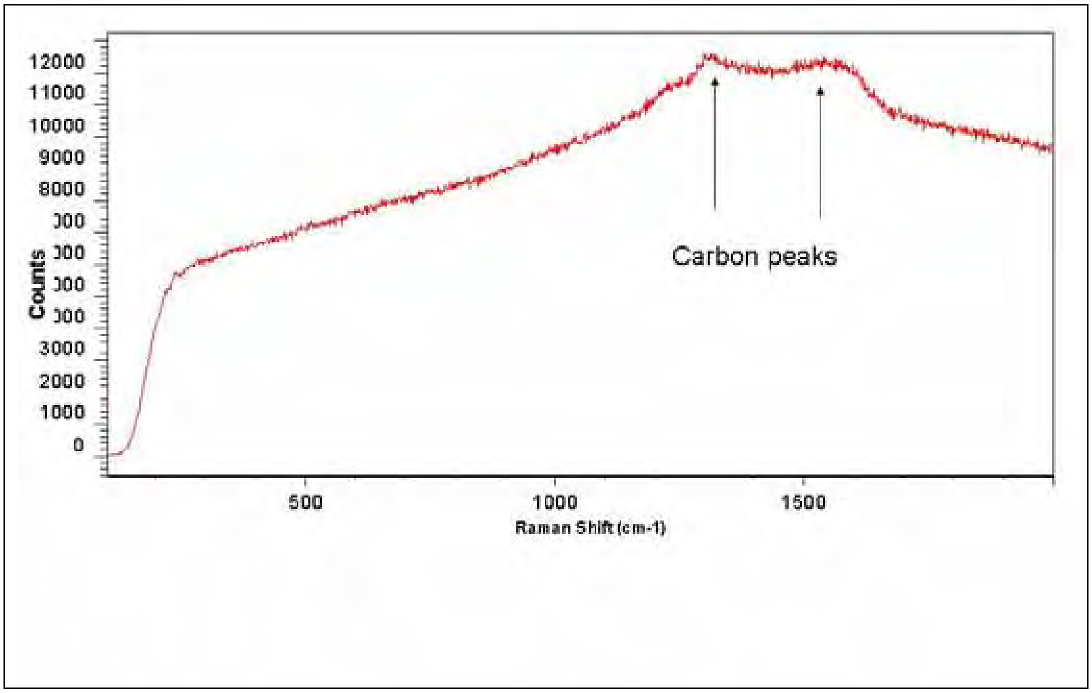


Figure C.29 Raman spectrum of ridges on spout interior surface. These ridges or mounds cover tension cracks; the Raman signal confirms that these are organic in origin.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

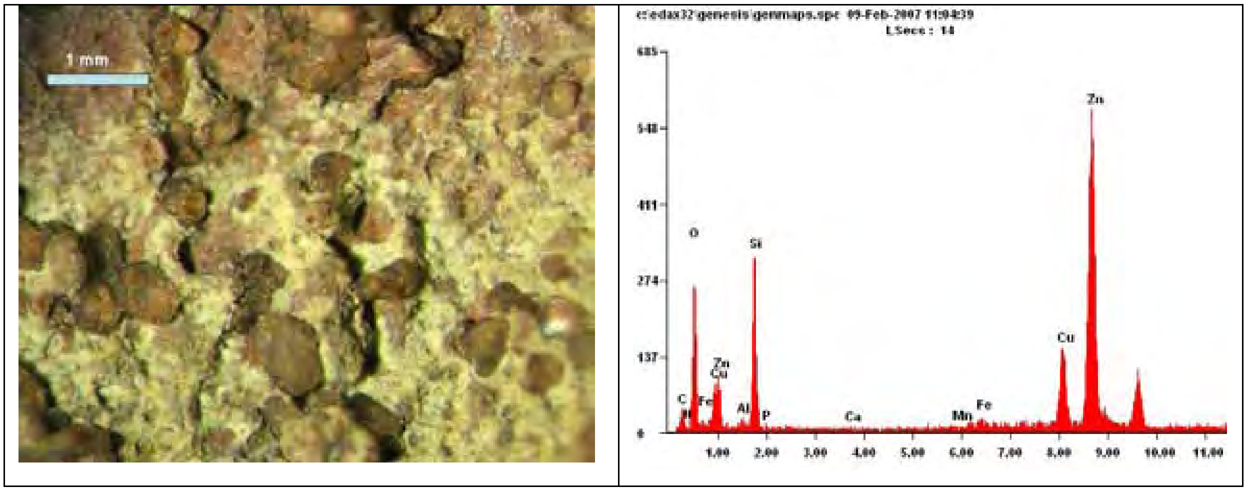


Figure C.30 Photomicrograph of interior of the spout holder (left) and EDS spectrum from the white portion of the scale (right). The large brown grains in the photograph are sand grains left from the original casting of the brass. They are partly surrounded by greenish scale (Cu carbonate) and whitish scale (Zn oxide). The Si in the spectrum is from quartz in the sand. Note also a small amount of Fe-Mn oxide, which imparts a brown stain to the quartz grains.

A peculiar situation was discovered in the analysis of the valve parts in Faucet 4. This unit was marketed as Envirobrass, in which Bi is used to replace Pb. Analysis of a duplicate faucet showed Pb contents to be quite low, ranging from below detection to 0.01 %. SEM-EDS analysis of the in movable valve parts (Figure C.31), however, showed high Pb and no Bi. These results were confirmed by X-ray fluorescence analysis of the parts.

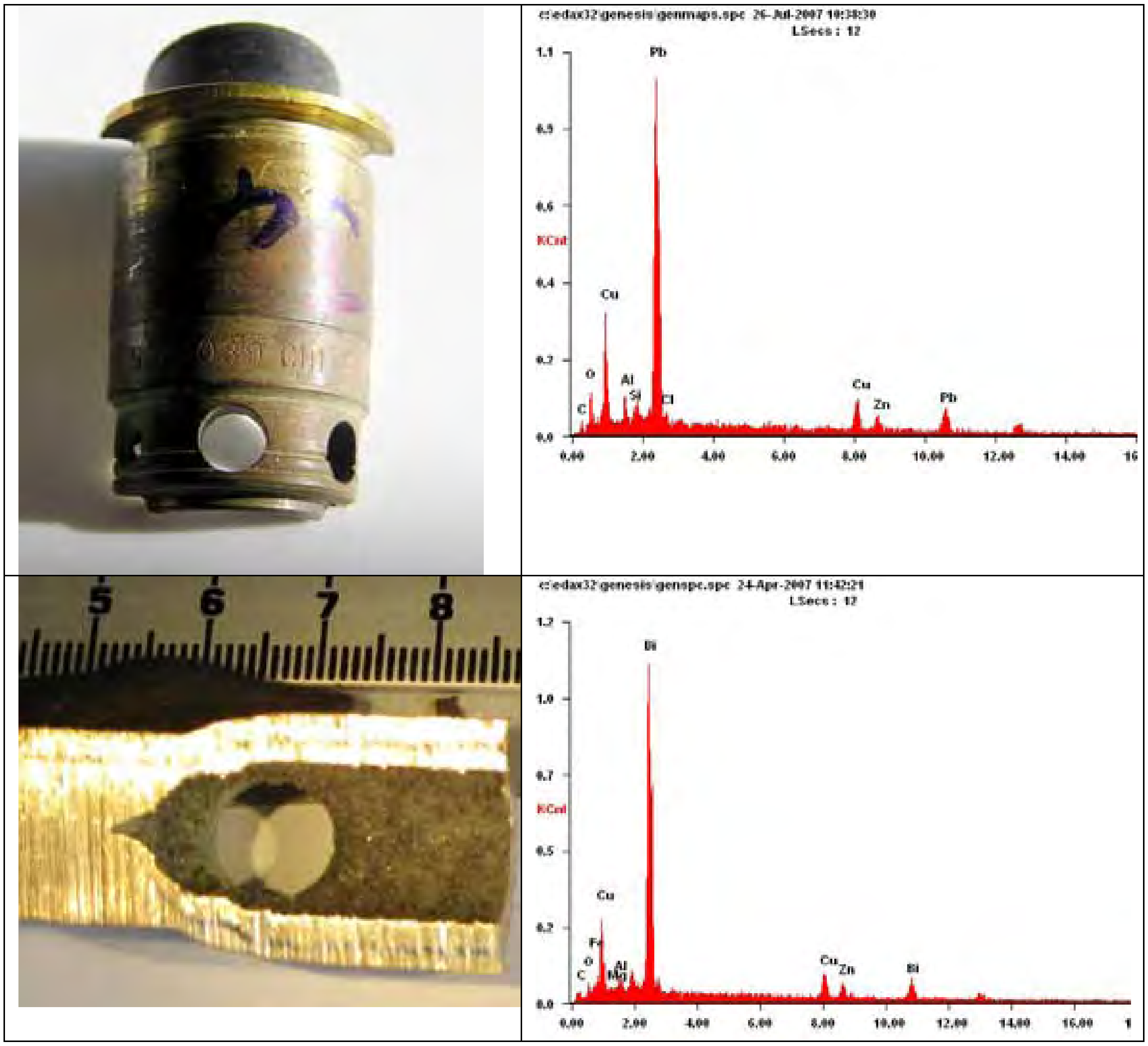


Figure C.31 Contrasting composition of different parts in Faucet 4. Top: Leaded brass used in the movable part of the valve. Lead-free brass used in the spout receiver.

Faucets 3, 5, and 6 showed no obvious scale development and had no obvious dezincification features.

Comparison of brass corrosion features to water chemistry results

Lead releases from the faucets, as determined in sequential sampling after 6 hour stagnation, tended to increase rather than decrease with time (Table C.12). This behavior is inconsistent with formation of passivating scale layers, but is consistent with progressive dezincification producing a porous surface layer through which Pb can diffuse more rapidly, or from which Pb particulates can be detached more readily with time.

In Table C.12, actual Pb, Cu, and Zn contents of the faucets tested, as determined by energy-dispersive spectroscopy, are also given. Using these values, there is a correlation

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

between Pb content of the faucets and the amount of Pb released, driven by the high Pb content of the valve in Faucet 4 (Figure C.32). There is, however, also a correlation with the Zn/Cu ratio of the brass (Figure C.33).

Table C.12
Pb extracted during sequential sampling, one liter aggregate sample

Date	Faucet 1 µg Pb	Faucet 2 µg Pb	Faucet 3 µg Pb	Faucet 4 µg Pb	Faucet 5 µg Pb	Faucet 6 µg Pb
10/20/2005	1.34	0.74	0.21	2.65	0.98	0.57
10/24/2005	1.52	1.16	0.21	0.39	0.86	0.51
10/27/2005	1.34	0.75	0.21	0.45	0.92	0.50
10/31/2005	1.28	0.92	0.27	0.39	0.92	0.45
11/7/2005	1.16	0.74	1.11	0.39	0.74	0.62
11/14/2005	2.54	0.62	0.15	0.27	0.68	0.39
1/12/2006	1.04	0.44	0.15	0.33	0.74	0.33
1/26/2006	0.86	0.33	0.27	1.71	0.44	0.44
2/9/2006	0.68	0.33	0.15	0.21	0.44	0.27
2/23/2006	0.68	0.27	0.27	0.21	0.39	1.71
3/23/2006	0.50	2.06	1.18	33.24	2.18	2.54
4/20/2006	0.39	0.21	0.15	8.26	0.44	0.44
5/18/2006	3.06	3.24	3.12	5.98	4.12	5.02
6/15/2006	0.38	0.32	0.21	0.45	0.21	0.33
7/24/2006	1.01	0.33	0.39	2.44	0.33	2.39
8/17/2006	0.33	0.50	0.21	0.33	16.10	2.02
9/7/2006	0.33	0.39	0.45	0.10	1.94	0.80
10/5/2006	0.68	0.45	0.50	8.72	1.89	5.90
11/2/2006	0.50	0.39	0.27	2.85	0.27	0.63
Avg. Pb, µg	1.03	0.75	0.50	3.65	1.82	1.36
Faucet %Pb	1.62	1.62	1.85	[1]5.59	2.35	2.17
Faucet Zn/Cu	0.75	0.92	0.67	0.47	0.65	0.64

[1] *SEM_EDS of valve used for Pb %*

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

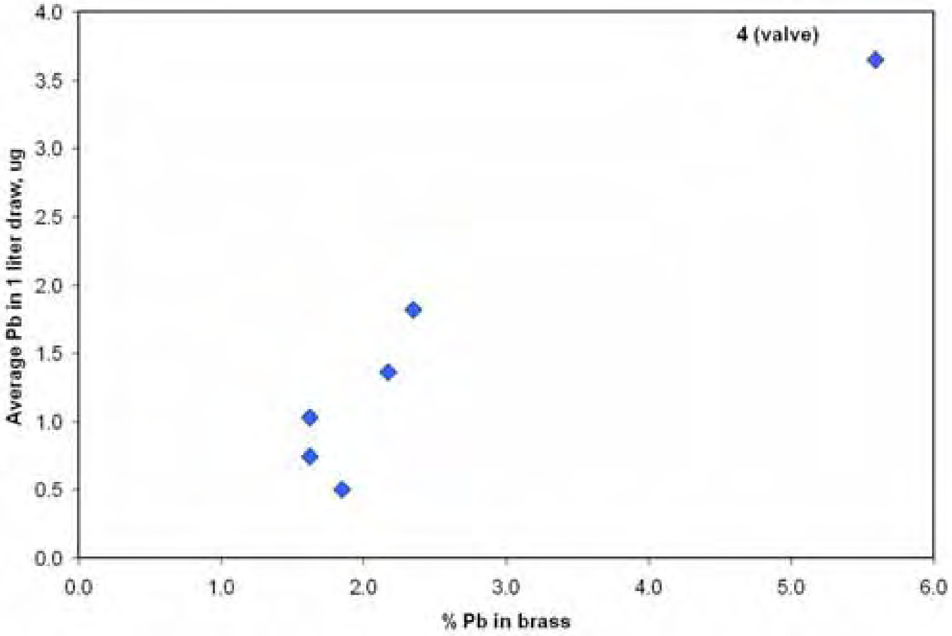


Figure C.32 Rate of Pb release as a function of Pb content of brass. The value for Faucet 4 is taken from the valve only; the rest of the faucet is < 1% Pb.

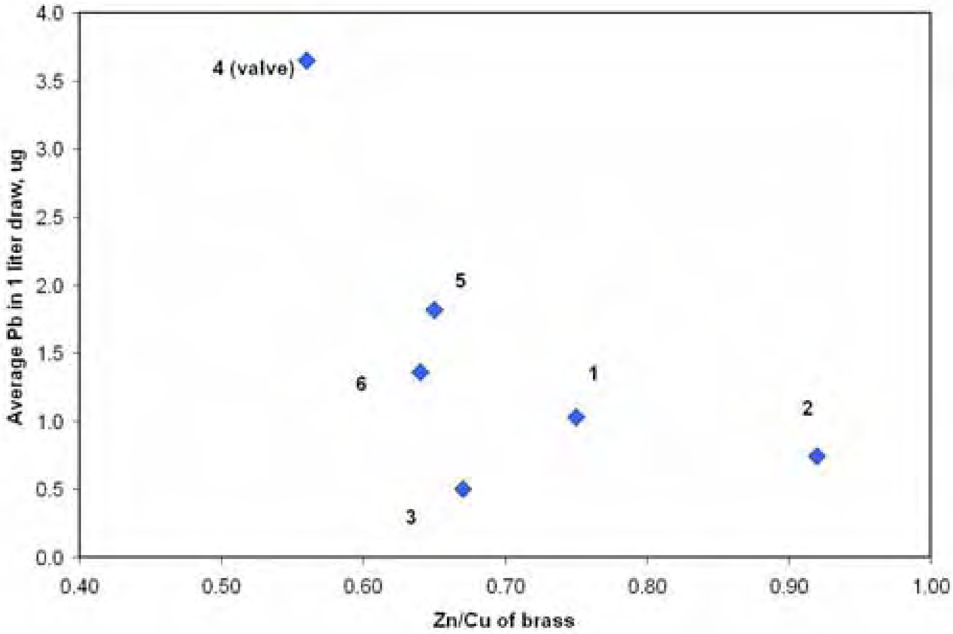


Figure C.33 Rate of Pb release as a function of Zn/Cu content of brass. The inverse relationship with Zn content is unexpected, but is shown dramatically by faucets 1 and 2, which are identical in all other aspects.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

The literature on brass corrosion indicates that dezincification should increase as the Zn content of the brass increases. Elements such as Al, As, and P are commonly added to brass in small amounts to retard dezincification. It is possible that the relationship shown in Figure C.33 reflects, say, arsenic content of the brasses, which could in turn be related to the Zn/Cu ratio. Most likely all the faucets have similar As contents, but none of these elements could be detected in EDS scans, however, and none were reported in the metal analyses of the duplicate faucets.

A more likely explanation of the results can be found in recent work by Marshakov (2005) on brass corrosion. He reports data from 〈-brasses of a variety of Zn contents in which the corrosion rate in stagnant water decreases with increasing Zn content, just as found in these experiments (Figure C.34, lower curve). In running water, however, the situation is reversed, with corrosion rate increasing with increasing Zn content (Figure C.34, upper curve).

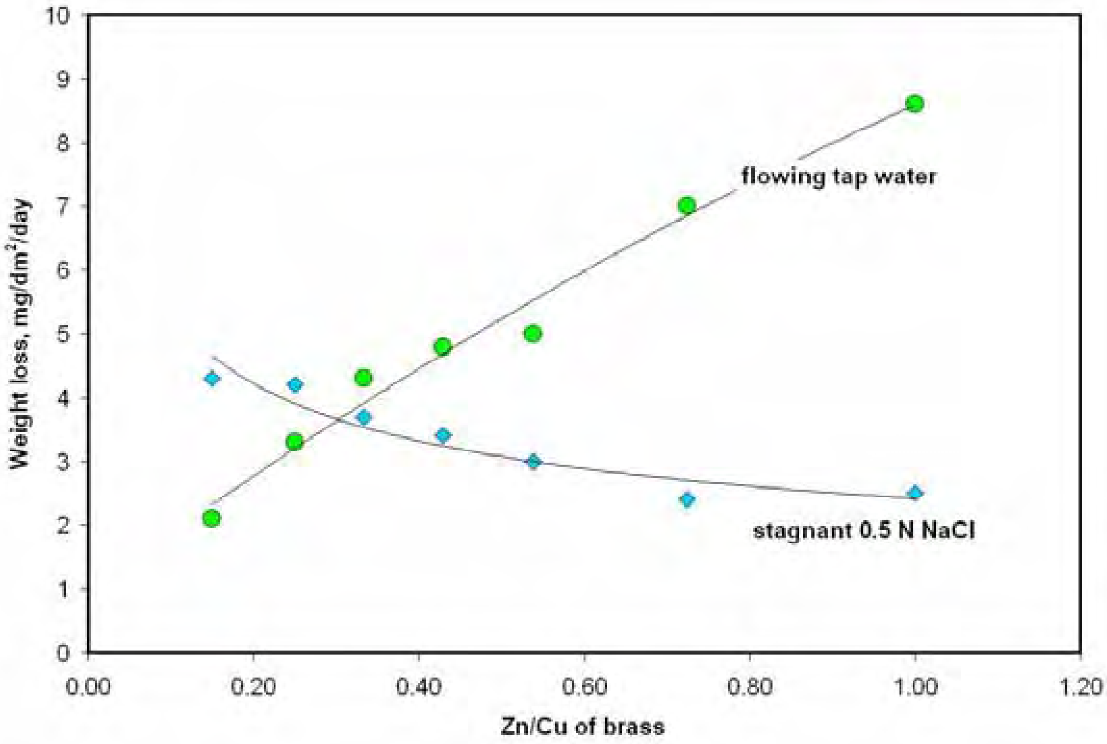


Figure C.34 Corrosion rates for brass coupons a function of Zn/Cu content of the brass. The r^2 values for the two functions are 0.982 and 0.985. Flowing 0.5 N NaCl produces similar results to the flowing tap water, but with rates about 2X higher.

The explanation for this contrast is that in the stagnant water, Cu^{2+} ions accumulate and catalyze the reaction

$$\text{Cu metal} + Cu^{2+} \longrightarrow 2Cu^{1+}$$

As long as oxygen remains in the water (Lytle and Schock, 2000), the cupric ions can be regenerated via

$$4Cu^{1+} + 4H^{+} + O_2 \longrightarrow 4Cu^{2+} + 2H_2O$$

and the reaction continues. See Rehan et al. (2001) for a discussion of these reactions.

The higher Cu brasses (those with lower Zn/Cu ratios in Figure C.34) release more Cu to solution in short stagnation cycles; therefore they corrode more quickly than lower Cu brasses. In flowing water, on the other hand, the buildup of the copper ions in solution is precluded, and the autocatalytic effect does not occur. In this case, the corrosion rate is controlled by the diffusion of Zn from the metal, which increases with increasing Zn content. This effect produces the relationship shown by the upper curve in Figure C.34.

Summary

Lead release from the six brass residential kitchen faucets tested at the PWB was found to be localized to a specific 60 mL sub-volume within a given faucet. However, since the actual internal volume of a faucet is only 95 to 201 mL, the net contribution of a faucet to a 1-L compliance sample is generally less than 3 µg/L. However, the faucets were also found to release random high concentrations of lead that would result in elevated concentrations in a calculated aggregate 1-L sample. In the worst-case, one faucet was found to have 33 µg/L of total lead in a aggregate 1-L sample. There was no differentiation between particulate and dissolved lead for this analysis. Approximately half of the lead in a 6-hour stagnation sample was released in the first 30 minutes of the stagnation period. The Envirobrass faucet was found to release 0.6 µg/L selenium or less for each of the subsamples taken, significantly less than the selenium MCL of 50 µg/L.

The sampling flow rate was found to have an impact on the total lead detected in 1-L samples from the faucets. The amount of lead detected correspondingly increased as the sampling flow rate increased from 1-L/min to 4-L/min. This correlation may be due to the increased scouring of the internal wetted surfaces. At the maximum flow rate (~8.3-L/min), lead release was found to decrease. This decrease may be the result of high volumes of water flushing through the faucet without an opportunity to mix high-lead boundary water into the bulk water and out into the sample.

A layer of amorphous minerals had accumulated onto the interior part of the faucet aerator during the twelve months of testing at the PWB. An elemental analysis determined that there was no lead retained in this layer. As a result, the aerators used in the PWB faucets did not accumulate particulate lead. The hypothesized reason is that the openings in the aerator are substantially larger than any lead particulates. As a result, any particulates released by the faucet body readily passed through the openings.

The individual components of the selected leaded brass faucets were manufactured from different materials, including brass with varying lead content, plastic, copper, and a non-leaded brass. Difference between the Envirobrass faucet and the leaded brass faucets was that the Envirobrass faucet replaced the leaded brass components with Envirobrass; the spout and cold water tube were the same materials as the other faucets. This testing found that there was no correlation between lead content in the metals and the amount of lead released during the PWB testing.

Testing triplicates of the PWB faucets using the ANSI/NSF Standard 61, Section 9 protocol found that some of the faucets exhibited substantial variability in lead release. The highest statistical lead Q value was from the faucet identified in the PWB testing as the one with the highest initial lead release, though this correlation may be coincidental since this particular faucet model exhibited among the greatest variability in the triplicates analyzed. In addition, the Standard 61, Section 9 protocol testing identified a high Q value for the Envirobrass faucet, which matches the high release detected during the long-term testing. Besides these two relationships, there was no correlation between the Standard 61, Section 9 testing with either the PWB tests or the metallurgical analysis.

Scale analysis indicated that none of the faucets showed extensive scale development, that is, passivating scales did not form over the one-year period of the experiment, although in some cases small patches of scale did form. Instead, the dominant process is the formation of a Zn-depleted layer on the internal surfaces of the faucets. Lead releases from the faucets, as determined in sequential sampling after 6 hour stagnation, tended to increase rather than decrease with time. This behavior is inconsistent with formation of passivating scale layers, but is consistent with progressive dezincification producing a porous surface layer through which Pb can diffuse more rapidly, or from which Pb particulates can be detached more readily with time.

PHREEQC modeling conducted on water quality conditions for Portland found that the only Pb mineral calculated to be at equilibrium with the water was the phosphate, pyromorphite. The mineral next closest to saturation was the carbonate, cerussite, but it is always somewhat undersaturated (negative saturation index).

Future Activities

The PWB water quality can be qualitatively described as a very soft surface water. As a result, mineral scaling in the interior parts of the faucet, especially in the aerators, is not a common phenomenon. Testing the faucets in a harder water may result in greater scaling in the interior of the faucet and the aerator, which in turn could limit the lead release from faucets as well as result in lead entrainment in a partially fouled aerator.

More investigation into how the results of the ANSI/NSF Standard 61, Section 9 correspond to real-world lead exposure from faucets is warranted. The testing on the five different types of faucets indicated that the Standard 61, Section 9 testing was able to predict the lead release from only one faucet (high Q value for Faucet 4 matched the relatively high lead release during the PWB testing). The results from the other faucets did not match, with faucets with high Q values exhibiting low release during the PWB testing while low Q value faucets were found to have relatively higher lead release. Given the variable nature of the individual faucet results, one potential future analysis would be to reevaluate if the use of only three faucets is sufficient to adequate to quantify lead release or if a larger number would be provide better answers with marginally increased costs.

The impact of sampling flow rate needs to be considered in sampling protocols. This analysis found that the flow rate had a direct impact on the levels of total lead detected in 1 L samples. The lowest results corresponded to the lowest sampling flow rate while the highest detected lead was at 4 L/min, with slightly lower results at the maximum flow rate. Some utilities, such as PWB, instruct the volunteer collecting the sample bottles to use a very low flow rate to prevent spilling or overflowing the sample bottle. While conducted for sample integrity, such a procedure could also result in lead concentrations that are potentially lower than the typical customer exposure in the first liter. In contrast, a sample collected at the highest flow rate (i.e. cold water valve full open) would potentially have higher lead results but includes the risk of sample loss. A more in-depth investigation should be conducted to determine if sampling flowrate should be included in compliance sampling procedures.

SEATTLE PUBLIC UTILITIES METER EVALUATION

Introduction

Lead (Pb) in drinking water was a concern for Seattle Public Utilities (SPU) even before the federal Lead and Copper Rule (LCR) was established in 1991. In the early 1970s, plumbing corrosion was recognized as not only an aesthetic nuisance but also as health and economic issues. Corrosion products from galvanized and copper pipe as well as solder and brass components can produce not only discolored water and the occasional green stained sink, but can result in high levels of Pb, cadmium, zinc, and copper in customers' tap water and reduce the life expectancy of their plumbing.

SPU has reduced the corrosivity of its soft surface waters with the addition of lime for increased alkalinity and pH adjustment from 7.2 to 8.2. The reduced metal leaching has increased service life for piping systems, caused fewer aesthetic problems, and perhaps most importantly, reduced ingestion of metals from drinking water. Now that compliance has been achieved with the LCR, SPU is evaluating other ways to reduce Pb exposure for its customers.

Although use of Pb solder and pipe has been discontinued, one of the few remaining sources of Pb in the drinking water is found in brass fittings and components. Typical brass alloys used in drinking water applications are produced with 4% - 8% Pb. Even after exposure of many years, this Pb can still be released into the drinking water. As part of this effort to reduce Pb exposure, SPU has participated in this AwwaRF project to analyze the impacts of brass water meters on Pb in drinking water.

Objective

A bench-scale study was conducted to examine metals release in residential brass water meters. This study simulated a typical residential setup in order to compare different water meters in side-by-side testing, with a focus on stagnation time and flushing rate with respect to meter age, manufacturer, and material type.

Methods and Materials

The experiments were conducted with a test rig installed at the SPU Water Quality Laboratory. The laboratory receives Cedar River drinking water, which is an unfiltered surface water. Aside from the water pH and alkalinity changes described previously, the only other changes to the water quality was the introduction of ozonation (for taste and odor control) and ultraviolet irradiation (for primary disinfection) in 2004. These last two changes are thought to have no significant impact on distribution system corrosion. The water quality entering the test rig during the testing period is listed in Table C.13.

Test Rig

The test rig was designed to simulate conditions in a typical residential plumbing system. A pressure regulator was installed at the head of the rig so that the meters were under a representative SPU main pressure (set to 60-70 psi) during the course of the study. Sample taps were placed at the outlet of each meter to allow samples to be collected at the normal distribution system pressure. Since the test rig was set up inside the SPU Water Quality Laboratory, the meters did not experience the full range of temperature swings or external corrosion as an in-ground meter might have.

Table C.13
Water Quality Measured Entering Test Rig

Parameter	Units	n	Average	Min.	Max.
pH	s.u.	6	8.24	7.96	8.72
Temperature	°C	6	10.9	8.5	13.5
Specific conductance	$\mu S/cm^2$	6	74.6	68.1	80.5
Dissolved oxygen	mg/L	6	12.7	12.1	13.1
Total alkalinity as CaCO3	mg/L	6	21.7	18.9	24.5
Chlorine, free	mg/L	6	1.05	0.87	1.30
Chlorine, total	mg/L	6	1.08	0.89	1.36
Total organic carbon	mg/L	6	0.90	0.85	0.98
Cu	mg/L	6	0.033	0.016	0.059
Pb	µg/L	6	0.49	0.28	0.84
Se	µg/L	6	<0.80	<0.80	<0.80
Bi	µg/L	6	<0.15	<0.15	0.15

The rig consisted of PVC pipe headers with the brass meters attached to 10-inch long sections of ¾-inch diameter commercial-grade copper pipe at each meter inlet, and 5-inch long copper pipes at each meter outlet (see Figure C.35). Since galvanic action could play a significant role in metals release, it was important to simulate as closely as possible the galvanic conditions the brass meter would experience in the distribution system. Though many older Seattle-area homes are still plumbed with galvanized iron pipe, the SPU standard for the last several decades has been to use a copper setter for residential service connections. Galvanized pipe is not commonly installed for new water service, and obtaining identical portions of used galvanized pipe would have been problematic. Prior to service, each section of copper pipe was de-burred, cleaned with a bottle brush and cleanser/detergent to remove any oils and dirt that could have promoted more intense local corrosion cells.

Afterwards, each of the pipes was conditioned for 43 days. Conditioning consisted of continuously passing fresh chlorinated tap water through the pipes in order to initiate the passivation process of the fresh copper surfaces in the pipe. Care was taken to ensure that all interior surfaces were fully wetted for the duration of the conditioning and that no air bubbles formed to limit metal-to-water contact.

Brass compression fittings were used to connect the copper pipes to the meters with Teflon tape to help seal the fittings. The interior of each fitting was coated with an epoxy resin to prevent the fittings from adding to background Pb levels. Electrical conductance was tested with a volt/ohm meter for each water meter section to verify galvanic action was unhindered.

Plastic rotameters were installed upstream of each meter to accurately measure the flow to each branch, and a plastic check valve was used to prevent any backflow during a sampling event. The rotameters and check valves contained small amounts of stainless steel, but the Pb and Cu released from these parts were estimated to be negligible. Plastic solenoid valves connected to timer controls maintained water flow through the meters. Surge arrestors were added to reduce water hammers from occurring with each valve actuation.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Figure C.35 Water meter test rig. Meters are numbered from left to right, with Meter 1 being the leftmost one and Meter 6 the rightmost.

Samples were collected by manually turning a ½-inch globe valve located in a tee between the outlet copper pipe and the flushing solenoid. Total metals samples were collected sequentially and acidified with 0.5% HNO_3. Dissolved metals samples were filtered through a 0.45-micron nylon filter before being acidified with 0.5% HNO_3. Both total and dissolved metals samples were allowed to stand for at least 24 hours after acidification before analysis. All metal analyses were conducted following USEPA Method 200.8 on an Elan 9000 ICP-MS. General water quality parameters were collected from a tee upstream of the inlet manifold prior to collecting meter samples. Dissolved oxygen and alkalinity were titrated with standardized reagents. Total and free chlorine were analyzed by a Hach PCL colorimeter.

Meter Selection

SPU has used various brands of meters throughout the years in response to new metering technologies and features and/or changes in available vendors. Four intact and fully functional ¾-inch brass residential water meters were removed from various locations in SPU's Cedar distribution system area, the same area in which the SPU Water Quality Laboratory is located. The ages and manufacturers of the meters are listed in Table C.14. Manufacturer B has been the standard model for the SPU system for the last 20 years. As noted previously, SPU used several different water meter manufacturers, which is why the older meters used in the rig are not all from the same manufacturer. Physical inspections of the meters prior to installing them in the test rig found no evidence of calcite depositions or other related minerals in the interior of the meters that would affect metal corrosion. Two new ¾-inch meters were also added to the test rig: a brass standard meter from Manufacturer B and a new meter made with Envirobrass, a brass that replaces nearly all of the Pb with bismuth (Bi) and selenium (Se). At the time of this study, the Envirobrass meter was not typically installed in the SPU system.

Table C.14
Water Meter Characteristics

Meter	Manufacturer	Meter Age (Years)	Internal Meter Volume (mL)[1]	Meter Body Metal
1	A	26	168	Leaded brass
2	B	19	212	Leaded brass
3	B	4	190	Leaded brass
4	C	40	278	Leaded brass
5	D	New	155	Envirobrass
6	B	New	177	Leaded brass

1. The 5- and 10-inches long, ¾-inch diameter copper pipes connecting each meter to the test rig had a total of 65 mL of internal volume in addition to meter volume.

Metal compositions of the meter bodies were determined prior to meter installations in the test rig. Table C.15 shows the results of the testing. The results show that the brass composition for Manufacturer B has not significantly varied for the past 2 decades and that only Meter 5 (Envirobrass) had significant concentrations of Bi and Se. The compositions were determined from metal shavings obtained from the exterior of the meters, beneath the surface corrosion. The shavings were acid-digested in 50 mL of heated HNO_3 and then diluted 100-fold using ultrapure laboratory-grade water prior to ICP-MS analysis. A metal compositions analysis of meter interiors was not conducted since the analysis required strong mechanical abrasion to remove existing corrosion scales and expose bare metal. In addition, the meters would have required dismantling, with the potential that the older meters could not be put back together afterwards. A separate test on a different set of meters of similar age and the same manufacturers found little difference in the metal composition between the interior and exterior of the meter bodies. The results of this separate test are included in Appendix A.

Table C.15
Meter Metal Composition

Meter	Element (%)						
	Pb	Cu	Zn	Fe	Se	Bi	Other
1	5.0	83.6	4.5	0.1	0.04	<0.1	6.6
2	6.8	80.1	7.9	0.2	<0.03	<0.1	4.9
3	7.0	80.9	8.8	0.2	<0.03	<0.1	3.1
4	6.5	79.4	9.6	0.1	<0.03	<0.1	4.4
5	0.03	90.0	5.7	<0.1	0.33	1.73	1.7
6	6.7	79.0	8.2	0.2	<0.03	0.1	5.8

Results and Discussion

Although precautions were taken to limit physical disturbance, each meter experienced some shaking and jarring associated with their removal from the field, transport, and subsequent reattachment to the test rig. Since this action could have resulted in the disruption of the interior corrosion scales, each meter was flushed with tap water to stabilize the metal release from the equipment. Stabilization started on September 2, 2005 and constitutes Day 1 for using the meters in the laboratory testing. Once stabilization was achieved, two experiments were conducted. The first experiment was to quantify the metal release from the meters during 4 months of simulated residential use with 6-hour stagnation times. The second was to determine the impact of varying the stagnation times on metal release. The results from the stabilization period and the 2 experiments are described below.

Baseline Stabilization

The baseline stabilization consisted of flushing tap water through the meters at the low rate of 1 L/min intermittently for a total of 3 hours/day. Meter stabilization started on September 2, 2005 and ended on December 12, 2005, a duration of 101 days. Six-hour stagnation samples, each 250 mL in volume, were collected from the meters, generally at 1-week intervals.

Figures C.36 and C.37 show the total amount of Pb detected in the flowing water samples from Meters 1, 2, 3, 5, and 6. Meters 2 and 3 were found to have similar Pb levels during the stabilization period. Since the meters had similar Pb content, these results would indicate that the corrosion rate has varied little between 4 and 19 years of use. Meter 1 was found to release less Pb than Meters 2 and 3 possibly because it had less Pb in the brass body and was an older meter. Meter 5, the Envirobrass meter, was found to release 1 – 2 µg/L of Pb, which was the lowest level of all the meters. This result was anticipated since even though the meter was new, and the internal surface was not passivated to limit metal corrosion, the meter had the lowest amount of Pb in the body. Finally, Meter 6 released Pb at or in excess of 15 µg/L, the LCR 90th percentile action level (AL) for the duration of the period. This was a new leaded brass meter with little or no corrosion scale on the interior surfaces.

Results for Meter 4 are plotted separately on Figure C.37 with a larger y-axis scale. Meter 4 had been accidentally dropped during removal from the field while all the other meters avoided such disruptions. Elevated Pb concentrations were suspected to be the result of the physical jarring and subsequent release of internal corrosion scales. The data indicates that 63 days were required to re-stabilize the scales and reduce Pb release to below the AL.

The Cu concentrations detected in the same samples are shown in Figure C.38. All meters except Meter 4 consistently showed very low Cu concentrations. The Meter 4 Cu results were high and correlated strongly with the Pb results, which supports the hypothesis that the elevated metal concentrations were due to the physical disruption of the corrosion scales.

For this period, Se from the new Envirobrass Meter 5 ranged from <0.80 µg/L (the method reporting limit [MRL]) to 1.6 µg/L, while Bi was between 0.10 and 0.60 µg/L (Figures C.39 and C.40). The maximum contaminant level (MCL) for Se is 50 µg/L while there is no Bi MCL. Results from the other meters were generally at or less than the Se and Bi MRLs (0.15 µg/L for Bi).

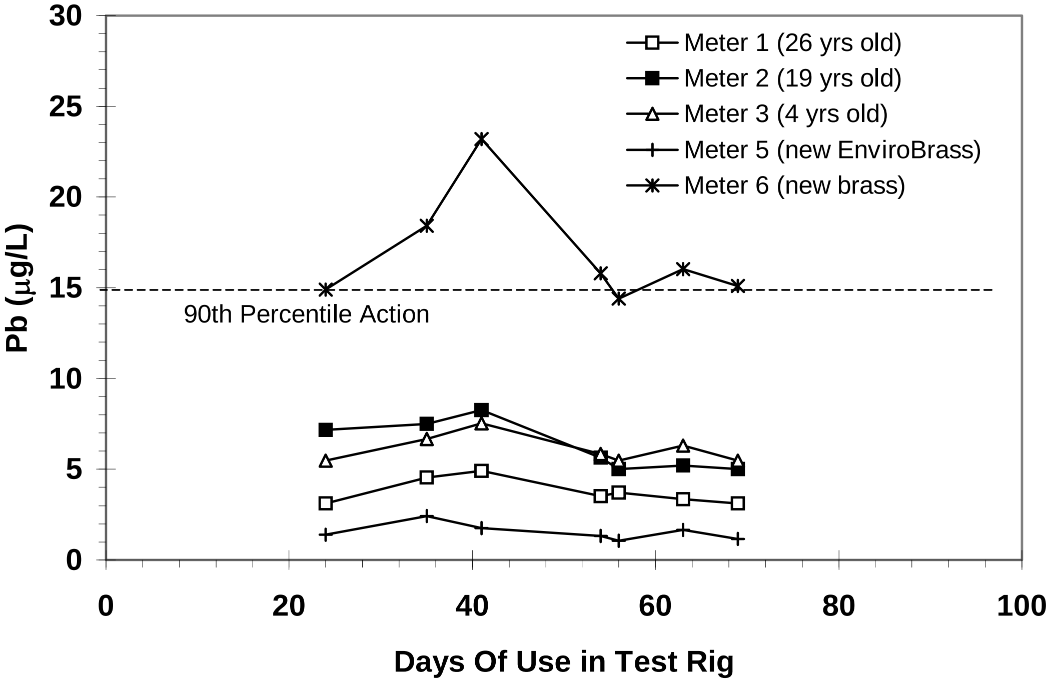


Figure C.36 Total Pb detected in 250-mL 6-hour stagnation samples from stabilization period for Meters 1, 2, 3, 5, and 6. Stabilization period ends on Day 101.

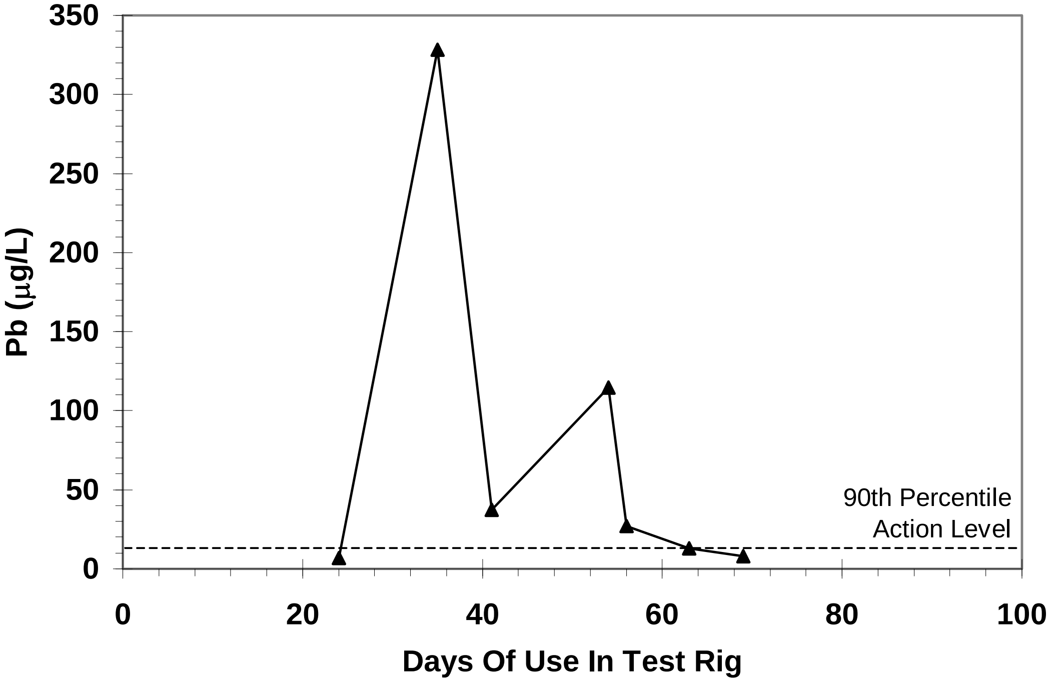


Figure C.37 Total Pb detected in 250-mL 6-hour stagnation samples from stabilization period for Meter 4. Stabilization period ends on Day 101.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

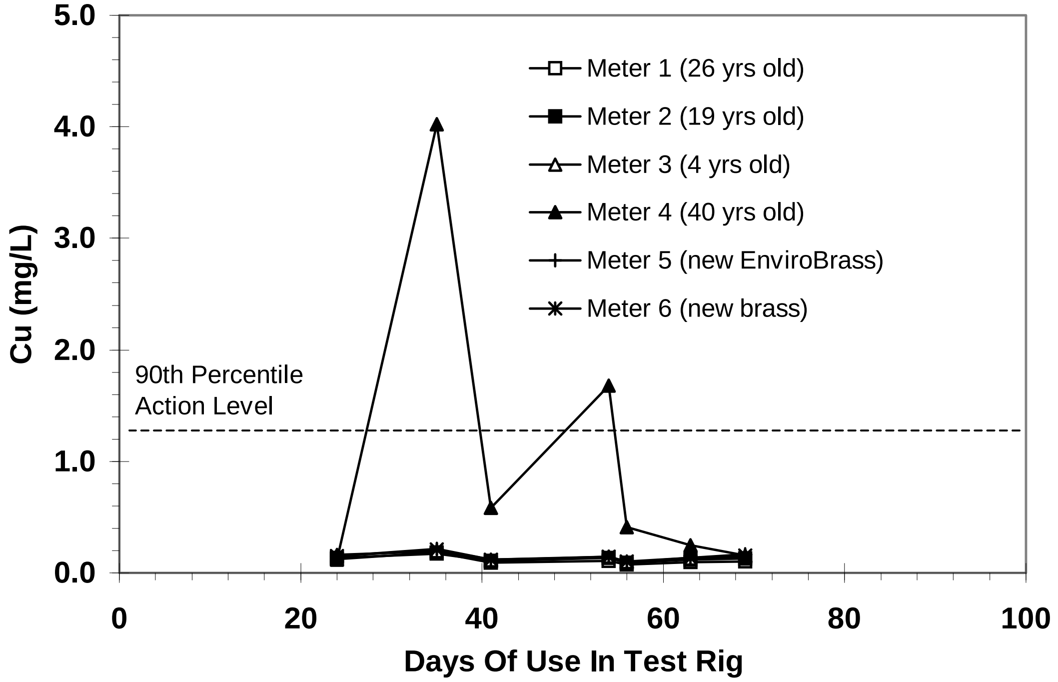


Figure C.38 Total Cu detected in 250-mL 6-hour stagnation samples from stabilization period for all meters. Stabilization period ends on Day 101.

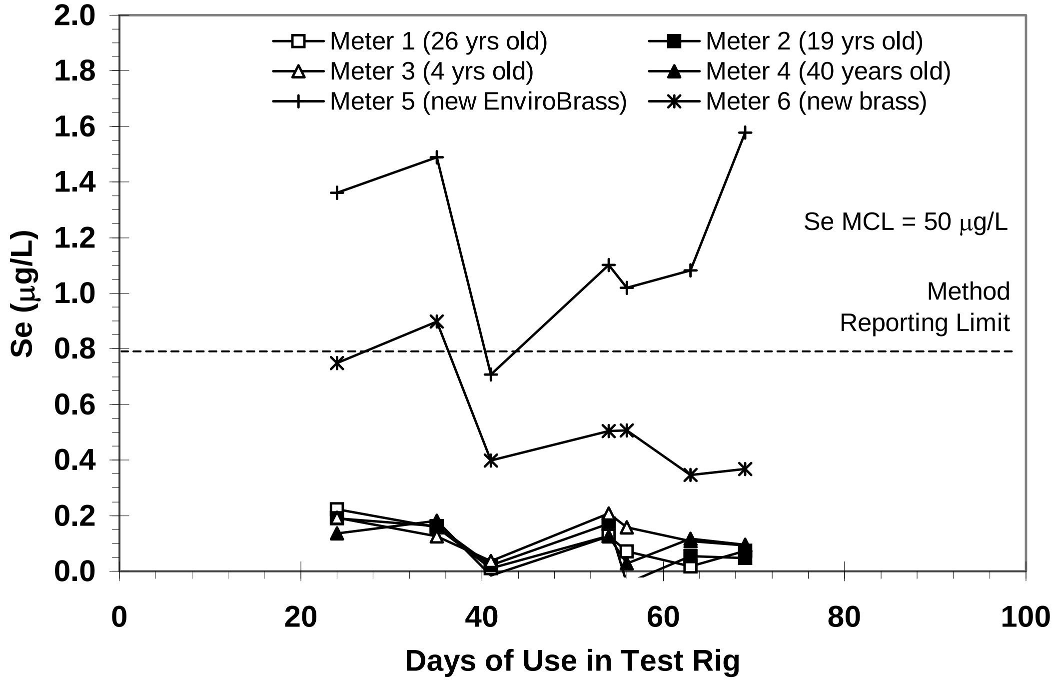


Figure C.39 Total Se detected in 250-mL 6-hour stagnation samples from stabilization period for all meters. Stabilization period ends on Day 101.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

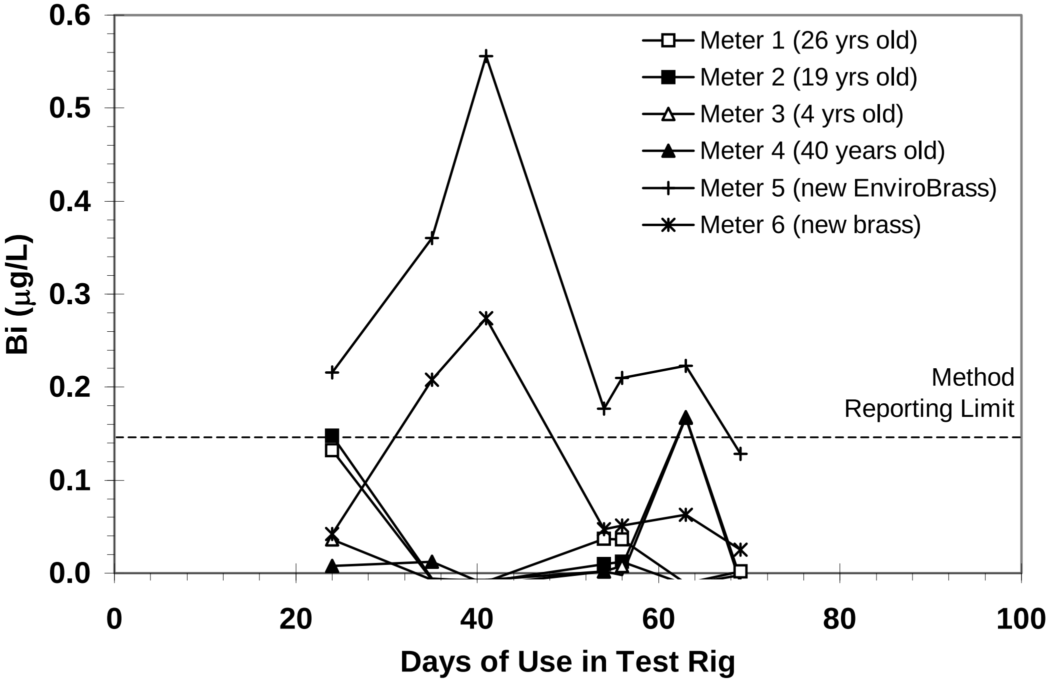


Figure C.40 Total Bi detected in 250-mL 6-hour stagnation samples from stabilization period for all meters. Stabilization period ends on Day 101.

Metal Release with Simulated Long-term Use

The long-term experiment started after the metals release from meters was determined to have stabilized. The experiment consisted of passing water through the meters at an initial rate of 1 L/min at various times throughout a 24-hour period to simulate typical residential water use. The ON/OFF cycle is listed in Table C.16. After 6 weeks, the flow rate was increased to 4 L/min to determine the potential impact of flow rate on Pb release.

Three sets of water samples were obtained from the water meters over a 2-month period. The samples were collected after a 6-hour stagnation period, which is the stagnation period required for LCR compliance samples (USEPA, 1991). Each sample set consisted of 5 sequential samples with volumes (in order of sampling) of 125 mL, 125 mL, 250 mL, 250 mL, and 1 L. Collection of the first 2 samples would remove all, or at least the majority, of the water that had been stagnant inside the meters, with subsequent samples containing water that had not been in contact with the meter during the 6-hour period. Each sample was analyzed for the concentration of total metals. The first 125 mL sample was also filtered and analyzed for dissolved metals.

Test at 1 L/min Flow Rate – Pb results from the initial flow rate of 1 L/min are shown in Figures C.41 through C.45. The graphs show the cumulative mass detected in the sequential samples. A line has been added to the graphs to indicate the interpolated Pb mass that would have been present in a 1-L sample. As anticipated, Pb was generally found to be high in the first 2 samples due to the direct contact of the water with the meter during the stagnation period. The subsequent sequential samples generally had decreasing amounts of Pb due to the dilution of any residual stagnant water inside the meter. Most of the Pb had been flushed out after a total of 500 mL to 750 mL of water had passed through meter. The exception to this observation was

Meter 1. The Pb concentration did not seem to plateau but continued to increase through the 1,750 mL volume. The increasing Pb in the flushed aliquots may be a function of the low flow rate and physical design of the meter, which might be causing turbulent flow conditions through the meter. As will be discussed later, the Pb results from this meter using a flow rate of 4 L/min were more stable than those shown in Figure C.41.

Table C.16
Simulated Residential Water Use ON/OFF Cycle Times

Time	Water Flow	Comment
7:30 AM – 8:30 AM	ON	
8:30 AM – 3:00 PM	OFF	Water sampled at 2:30 PM for 6-hour stagnation period.
3:00 PM – 4:00 PM	ON	
4:00 PM – 7:00 PM	OFF	
7:00 PM – 8:30 PM	ON	
8:30 PM – 7:30 AM	OFF	

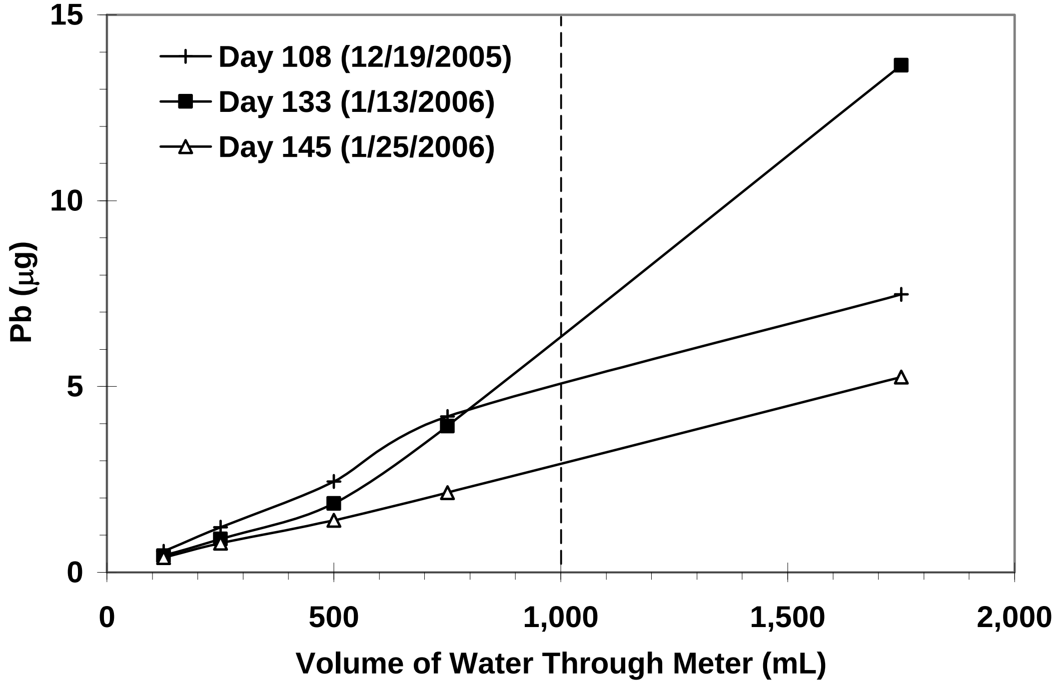


Figure C.41 Cumulative total Pb mass in Meter 1 – 26 years old (6-hour stagnation samples from simulated use at 1 L/min).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

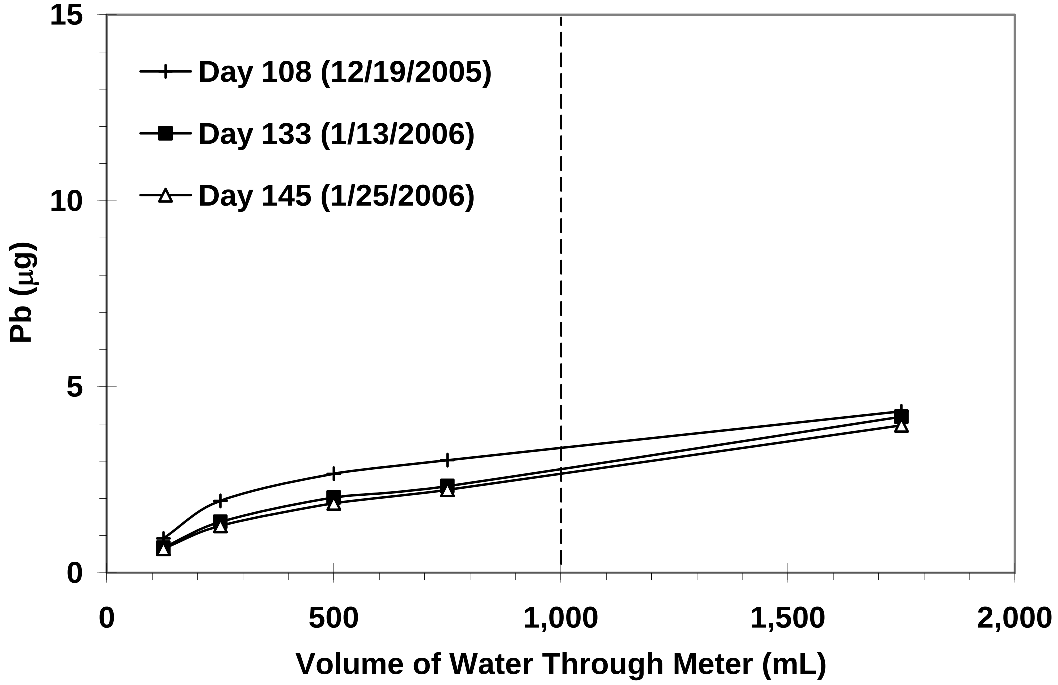


Figure C.42 Cumulative total Pb mass in Meter 2 – 19 years old (6-hour stagnation samples from simulated use at 1 L/min).

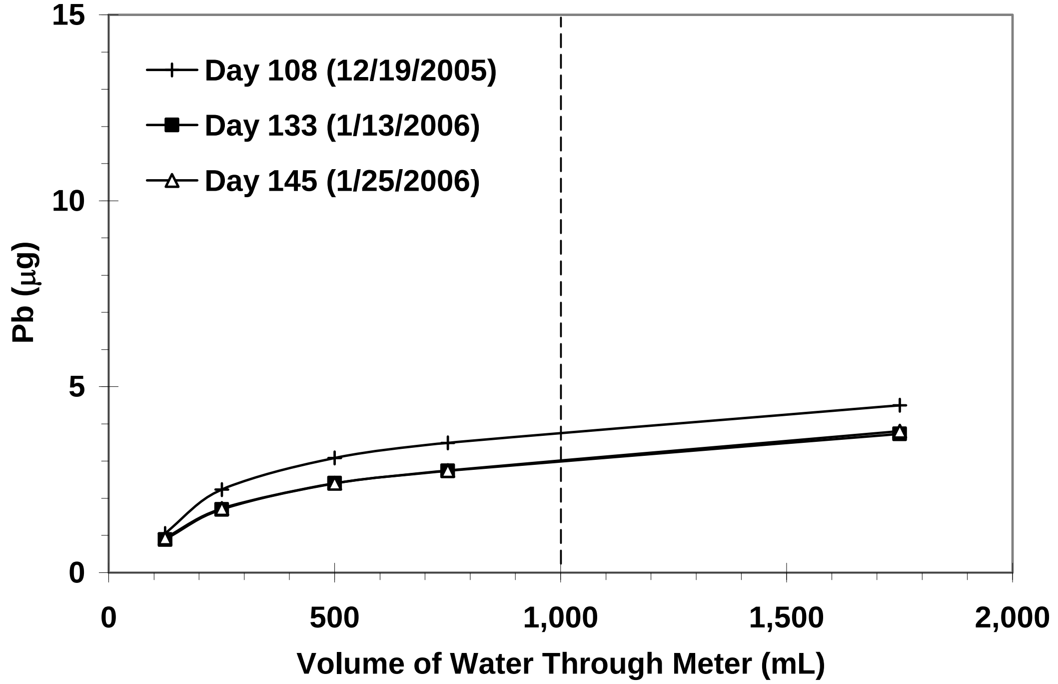


Figure C.43 Cumulative total Pb mass in Meter 3 – 4 years old (6-hour stagnation samples from simulated use at 1 L/min).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

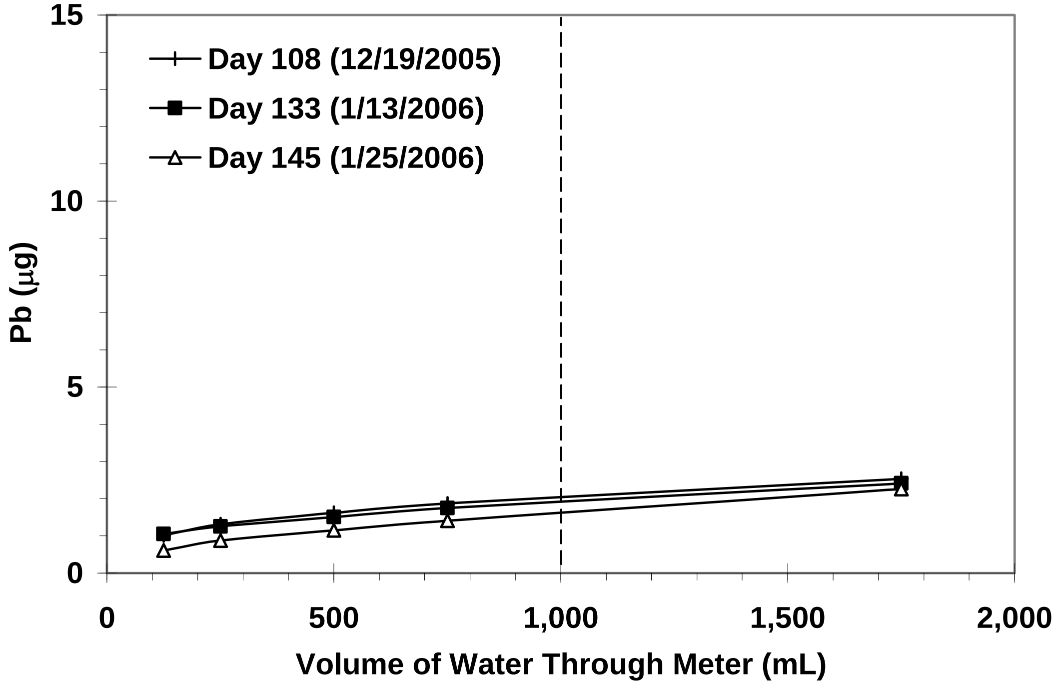


Figure C.44 Cumulative total Pb mass in Meter 4 – 40 years old (6-hour stagnation samples from simulated use at 1 L/min).

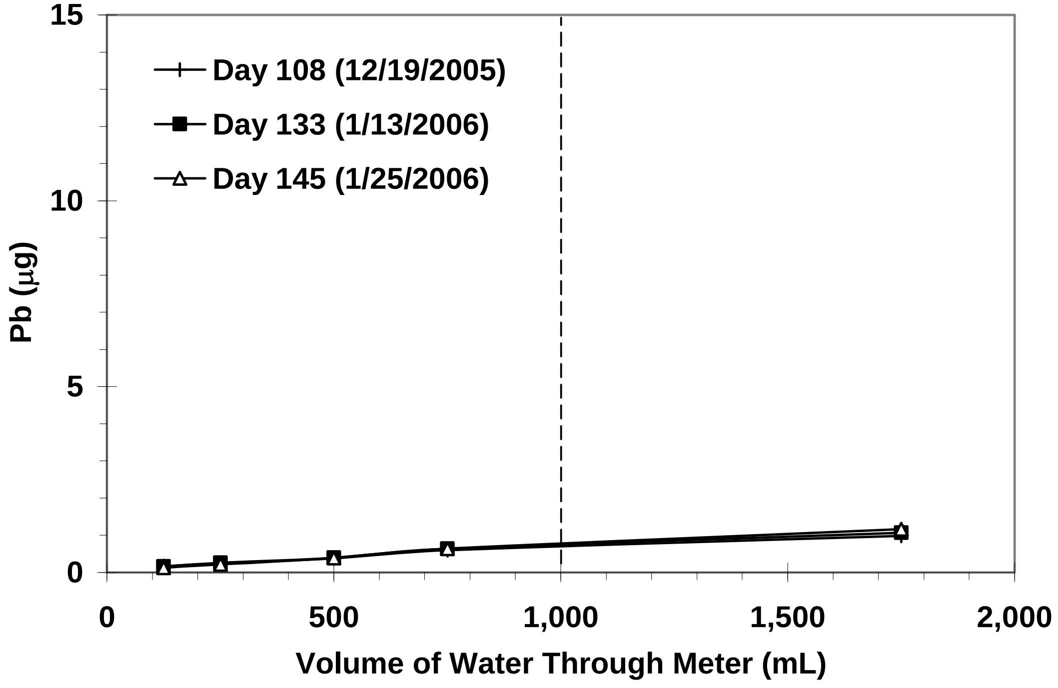


Figure C.45 Cumulative total Pb mass in Meter 5 – new Envirobrass (6-hour stagnation samples).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

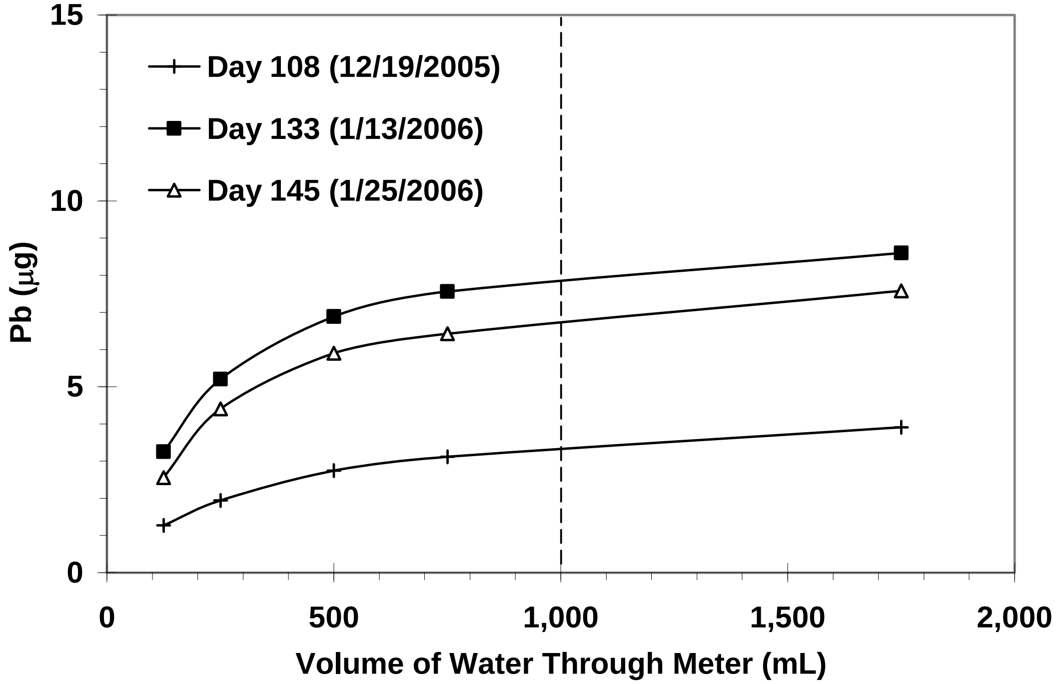


Figure C.46 Cumulative total Pb mass in Meter 6 – new leaded brass (6-hour stagnation samples from simulated use at 1 L/min).

Results for Meters 2 and 3 are very similar, which further supports the idea that Pb leaching from these meters in the SPU system does not vary much after 4 years of use. Meter 4 had comparable Pb mass in the first 125 mL samples but lower amounts in all subsequent samples. The difference is suspected to be the result of either the differing internal volumes or the physical configuration of the meters, which would affect the mixing and release of the stagnation water and any particulates from the meter.

The dissolved fraction of the Pb in the first 125 mL sample was found to vary between 23% and 77% of total Pb mass for the 4 used meters (Meters 1 through 4) with Meter 4 having the lowest dissolved Pb mass (see Figure C.47). The hypothesis for these results is that dropping the meter mechanically weakened the bonding strength between the scales and the underlying metal. The stabilization period scoured away many of the loosened scales but apparently not all, as continued intermittent flow through the meter continued to result in higher concentrations of particulate Pb.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

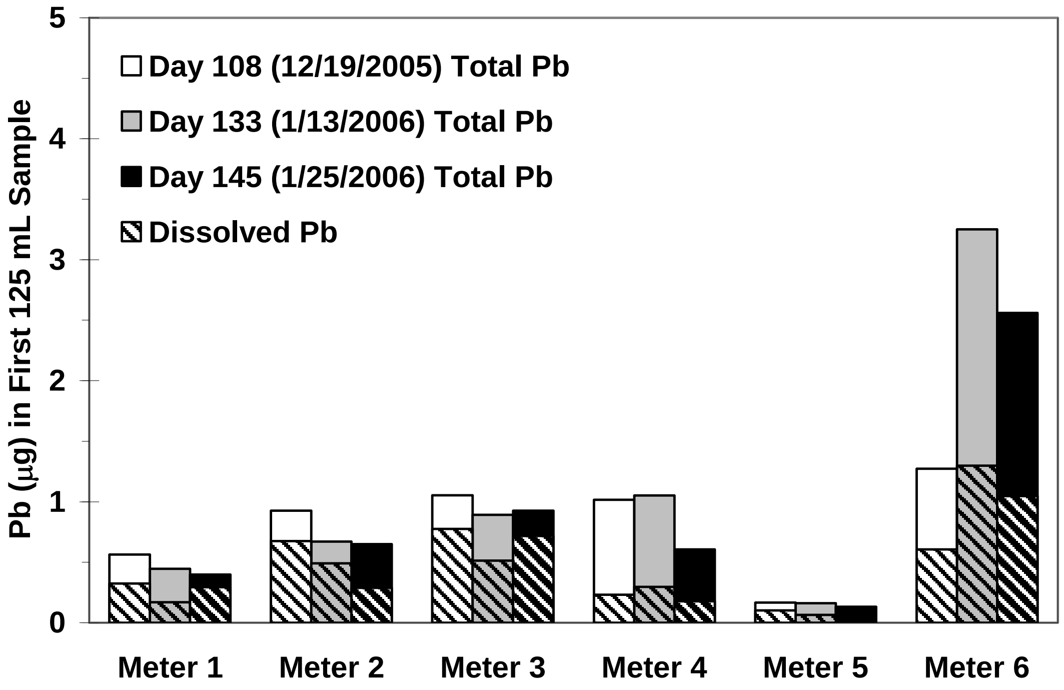


Figure C.47 Comparison of total and dissolved Pb in first 125 mL sample from each meter (6-hour stagnation samples from simulated use at 1 L/min).

The new Envirobrass meter (Meter 5) was found to have the lowest Pb release for all the meters tested. In comparison, the new leaded brass meter (Meter 6) had relatively high Pb amounts. These results seem to indicate that after 5 months of intermittent flow, the meter still had not formed similar internal corrosion scales as the older meters to limit metals release. Meter 6 was also found to have the highest amount of particulate Pb release.

Figure C.48 shows the previous data based on meter age using the last sampling date for the low-flow testing. This graph shows that with the Cedar water, Pb release decreased rapidly from meters between 5 months and 4 years of service for the brass meters produced from Manufacturer B, which had nearly the same metal composition (as noted in Table C.15). The change is believed to be due to the increasing passivation of the meter interior, which in turns limits the exposure of brass metal to the water. There was significantly less change between 4 years and 19 years of service life, which would indicate that the passivation is mostly stable at this point. If viewed solely on service life, and ignores differences in manufactured volumes or metals, there is a continued decline in Pb release. Granting this assumption, a conclusion could be made that there is a continued trend of passivation through out the meter service life. Due to the anomalous results for Meter 4, that the data for that particular meter was not included in the figure.

As with the stabilization period, Cu corrosion during the simulated residential water use test was found to be substantially below the 1.3 mg/L Cu 90th percentile AL. Figure C.49 shows the concentration data for Meter 6, which had the highest Cu results of the 6 meters, albeit only marginally more than the others. Cu concentrations slightly increased between each sampling date for Meter 6, which is a trend that was repeated all other meters. Given that the increases

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

were small for all meters and overall Cu results were well below the AL, the slight increase over time is most likely be the response to minor variations in the tap water quality at the time of sampling. Dissolved Cu was approximately 70 – 90% of the total Cu for each meter except Meter 4, the new Envirobrass one (see Figure C.50). Meter 4 was found to have the lowest fraction of dissolved Cu, and therefore the highest fraction of particulate Cu.

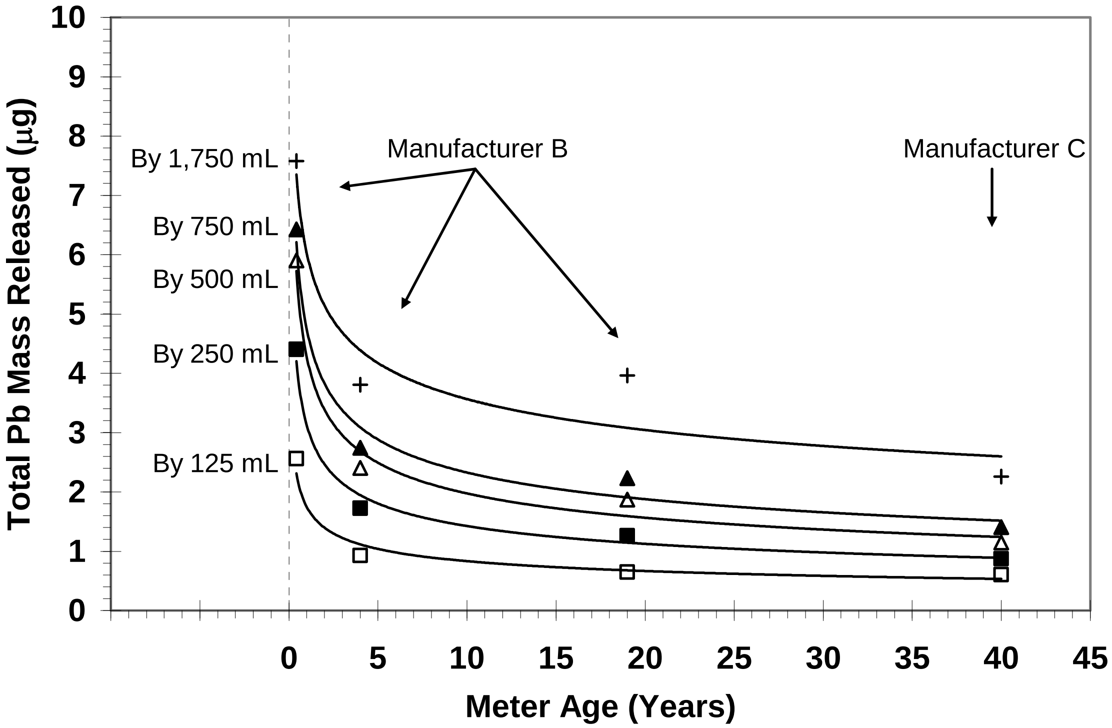


Figure C.48 Pb release as function of meter age and based on Jan. 25, 2006 sampling data (excluding Meter 1 [26 years]).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

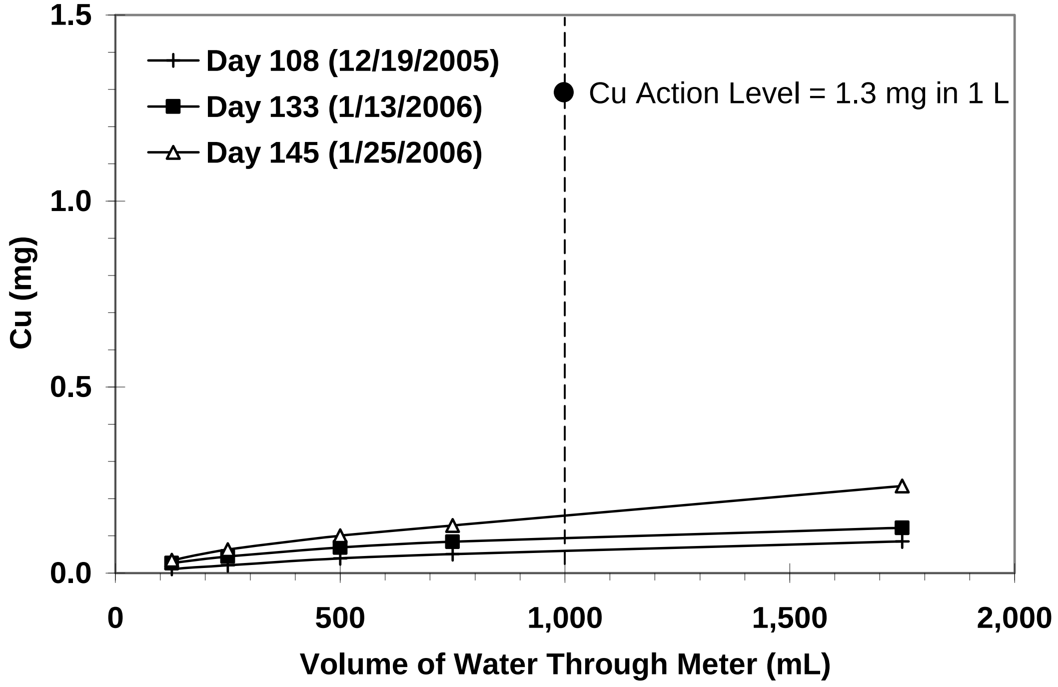


Figure C.49 Cumulative total Cu mass in Meter 6 – new leaded brass (6-hour stagnation samples from simulated use at 1 L/min).

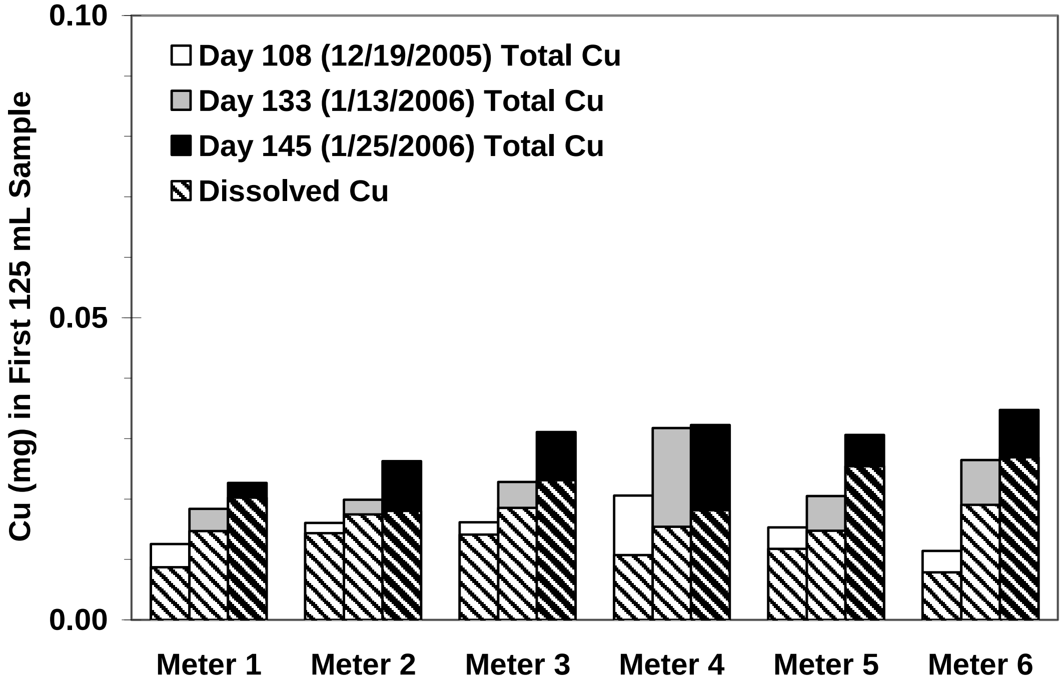


Figure C.50 Comparison of total and dissolved Cu in first 125 mL sample from each meter (6-hour stagnation samples from simulated use at 1 L/min).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Se concentrations in the Meter 5 samples are shown in Figure C.51. The results show that the metal is released at levels substantially below the MCL. Nearly all the metal was found to be in the dissolved form (see Figure C.52). Therefore, using Envirobrass to reduce Pb exposure would not result in any potential violation of another water quality standard. All Se results for the leaded brass meters were <0.80 µg/L. Such results were expected since Se could not be detected in 4 of the brass meters, it was detected at very low levels in the last meter, and these results matched those from the stabilization period shown in Figure C.51. The fractionation of total versus dissolved Se shows that nearly all the Se from every meter is in the dissolved form (see Figure C.52), though it must be stressed only the data for Meter 5 was above the ICP-MS MRL.

Similarly to Se, Bi analysis was at or below SPU's 0.15 µg/L MRL for the brass meters. Results for the Envirobrass Meter 5 are shown in Figure C.53. These results are informative only since Bi has no primary or secondary MCL. Particulate Bi accounted for 51% to 71% of the total Bi detected in the first 125 mL.

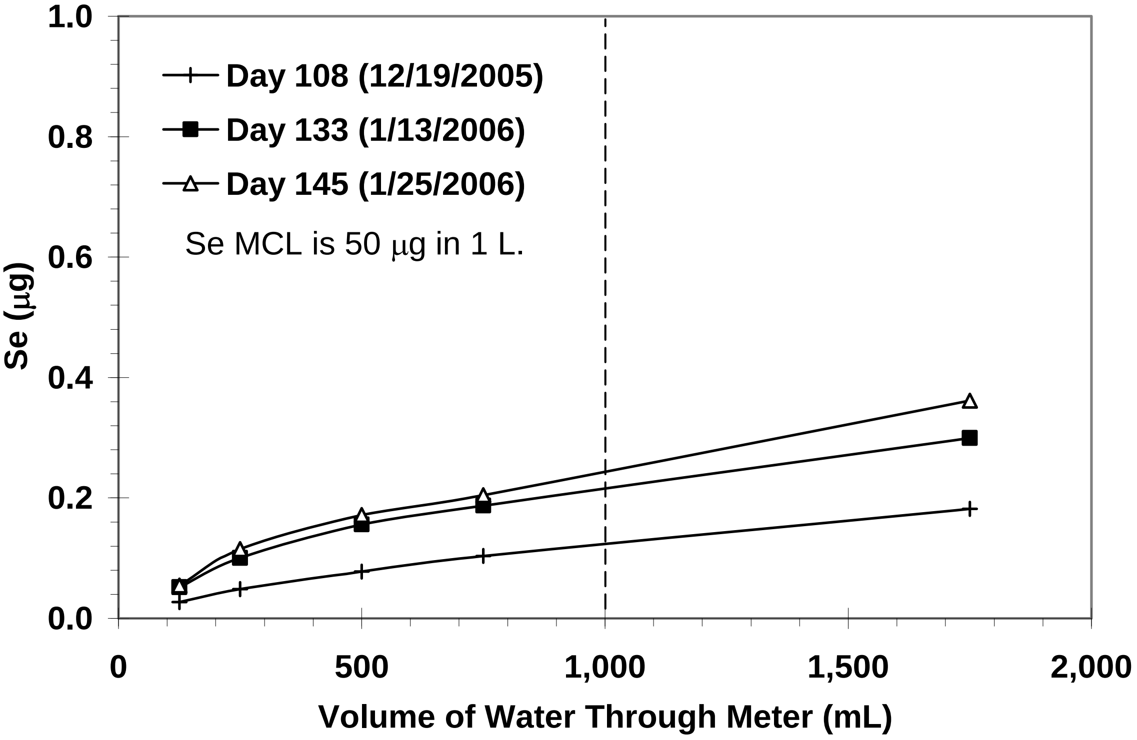


Figure C.51 Cumulative total Se mass in Meter 5 – new Envirobrass (6-hour stagnation samples from simulated use at 1 L/min).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

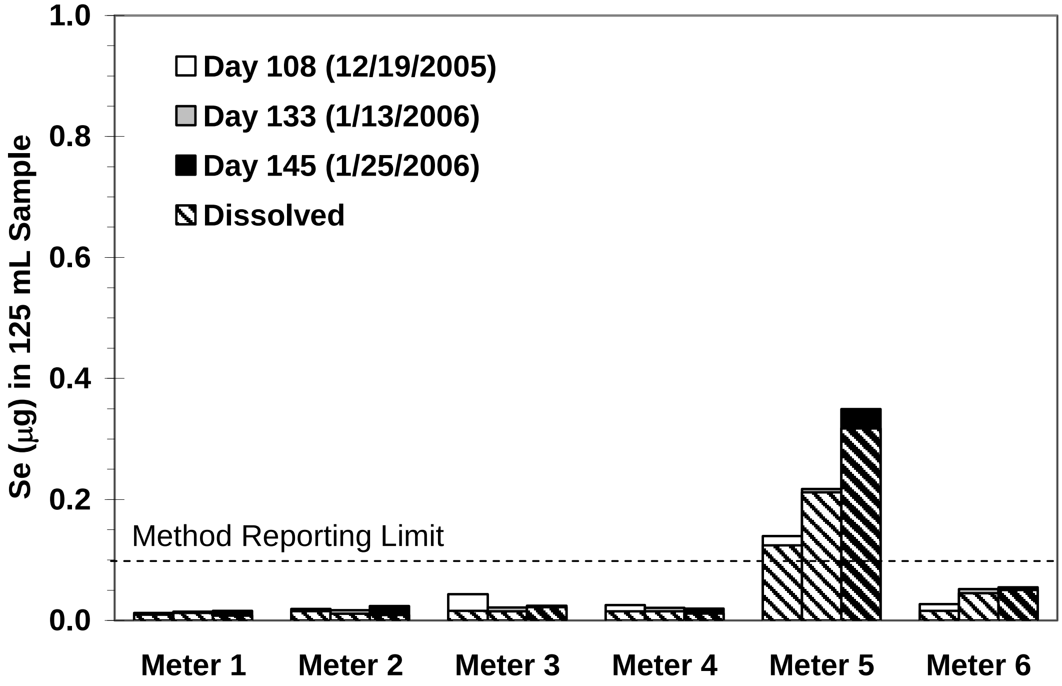


Figure C.52 Comparison of total and dissolved Se in first 125 mL sample from each meter (6-hour stagnation samples from simulated use at 1 L/min).

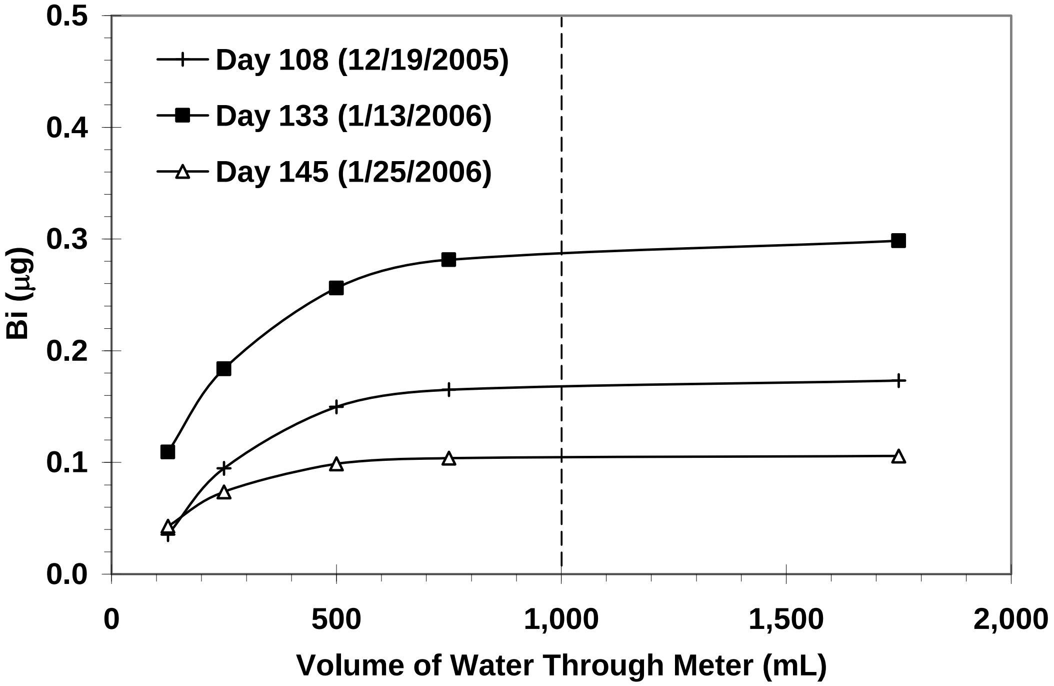


Figure C.53 Cumulative total Bi mass in Meter 5 – new Envirobrass (6-hour stagnation samples from simulated use at 1 L/min).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Test at 4 L/min Flow Rate – After Day 145 (January 25, 2006), the flow rate was increased to 4-L/min. Figures C.54 through C.59 show the results of cumulative Pb mass from the sequential sampling for this period. The results for Meter 1 (26 years) through the first 4 sequential samples (through 750 mL of Cedar tap water through the meter) followed the general asymptotic trend found in the other meters and not the earlier behavior of ever-increasing Pb. As a result, a comparison of the total Pb mass released after 1,750 mL between the two flowrates showed marked decrease at the higher flowrate (see Figure C.60). For the other older meters, the results from 4 L/min found that the cumulative mass of Pb released at the higher flowrate was essentially the same for Meters 2 (19 years) and 4 (40 years) and somewhat lower for Meter 3 (4 years). These results would indicate that the previously formed scales were sufficiently thick and/or adhered to the metal surface to resist being scoured away and exposing bare metal.

The new Envirobrass meter (Meter 5) also showed only a small increase with the flowrate change but still had the lowest amount of Pb released of all the meters. In contrast, Meter 6 (new leaded brass meter) did show a change in the mass of released Pb due to the flow rate change. Pb increased immediately with the increase in flow rate, which would indicate that the formed surface scales were being scoured from the meter interior and exposing bare brass. Yet, over the duration of 8 days, the Pb release decreased, which would indicate that corrosion scales were reforming over, and limiting the exposure of, the newly re-exposed metal.

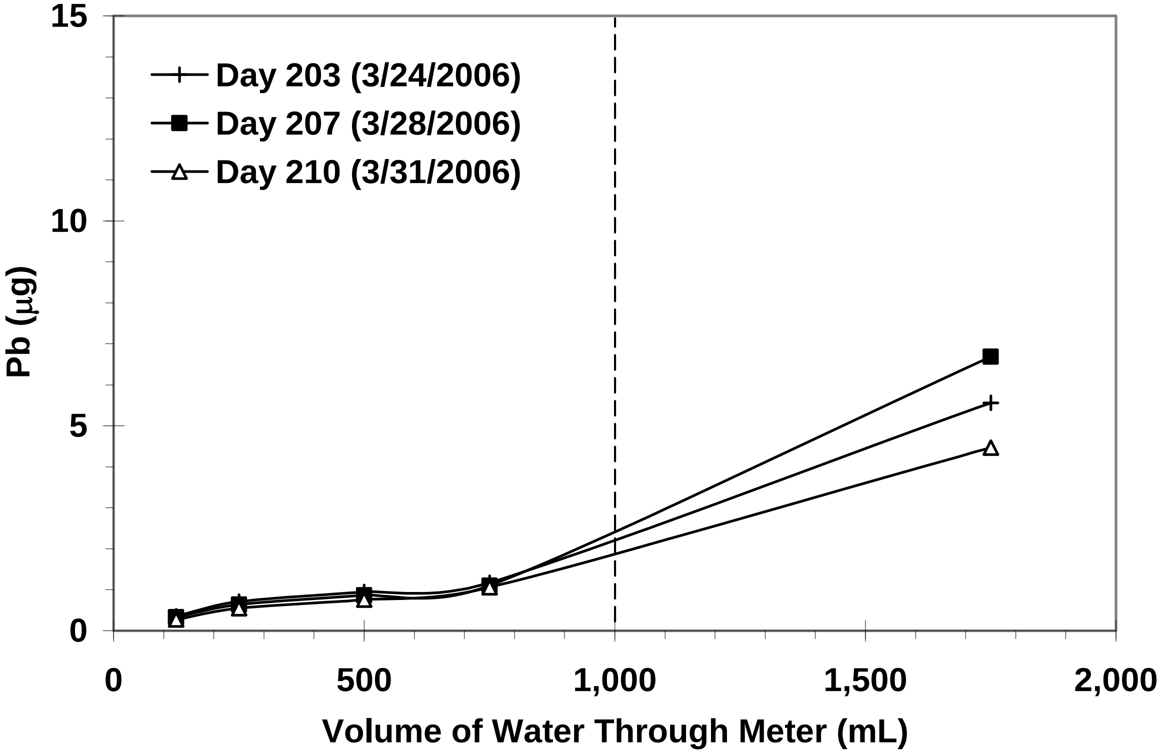


Figure C.54 Cumulative total Pb mass in Meter 1 – 26 years old (6-hour stagnation samples from simulated use at 4 L/min).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

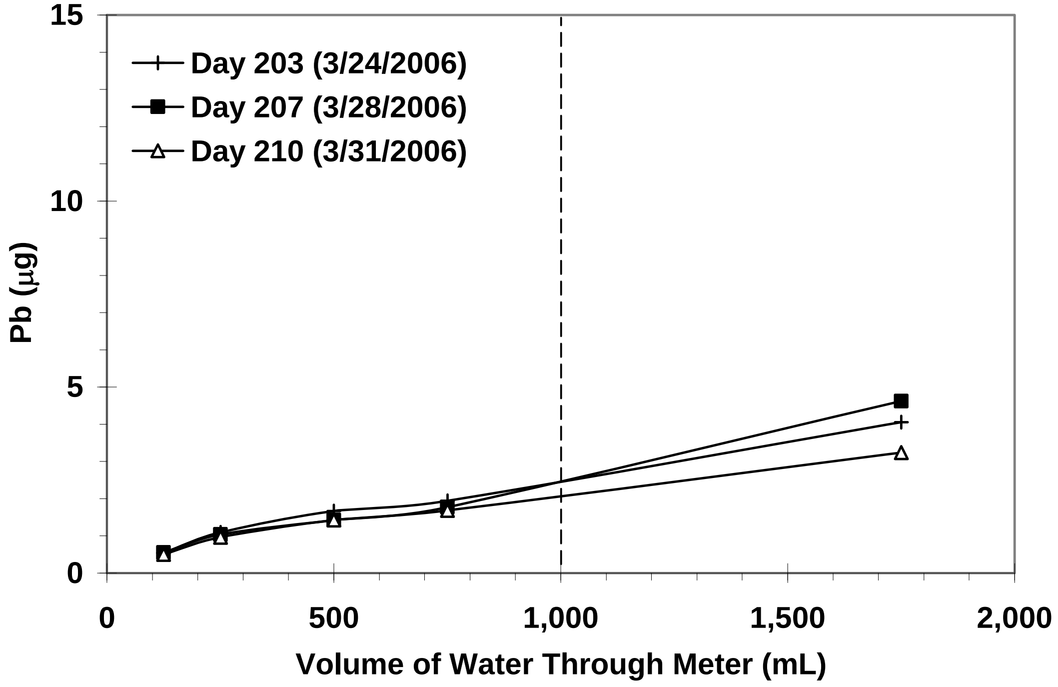


Figure C.55 Cumulative total Pb mass in Meter 2 – 19 years old (6-hour stagnation samples from simulated use at 4 L/min).

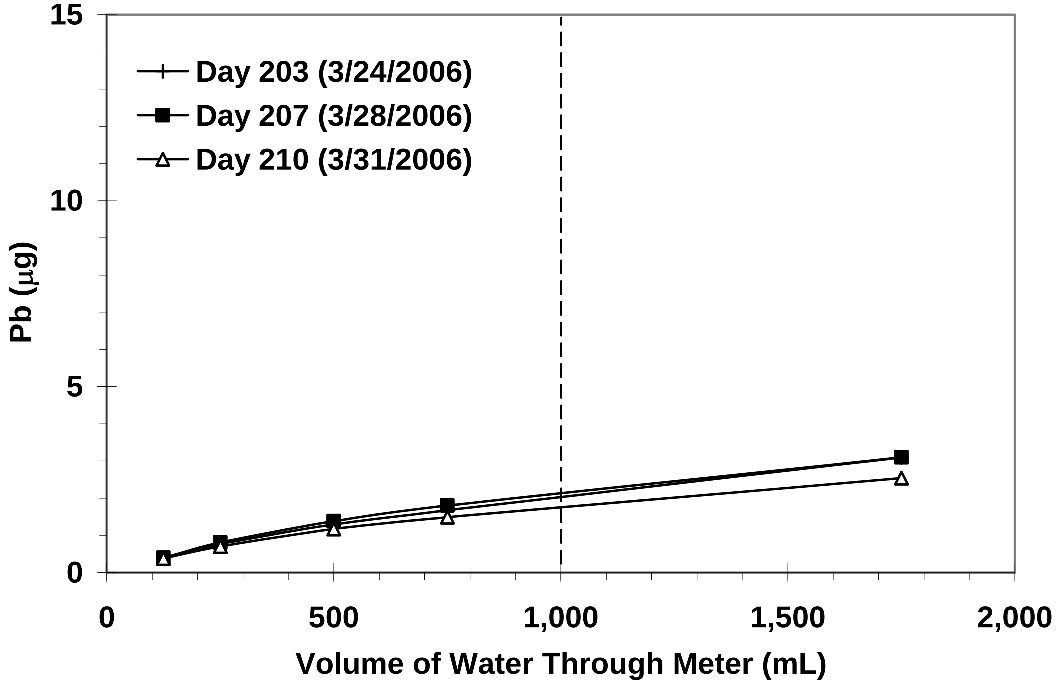


Figure C.56 Cumulative total Pb mass in Meter 3 – 4 years old (6-hour stagnation samples from simulated use at 4 L/min).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

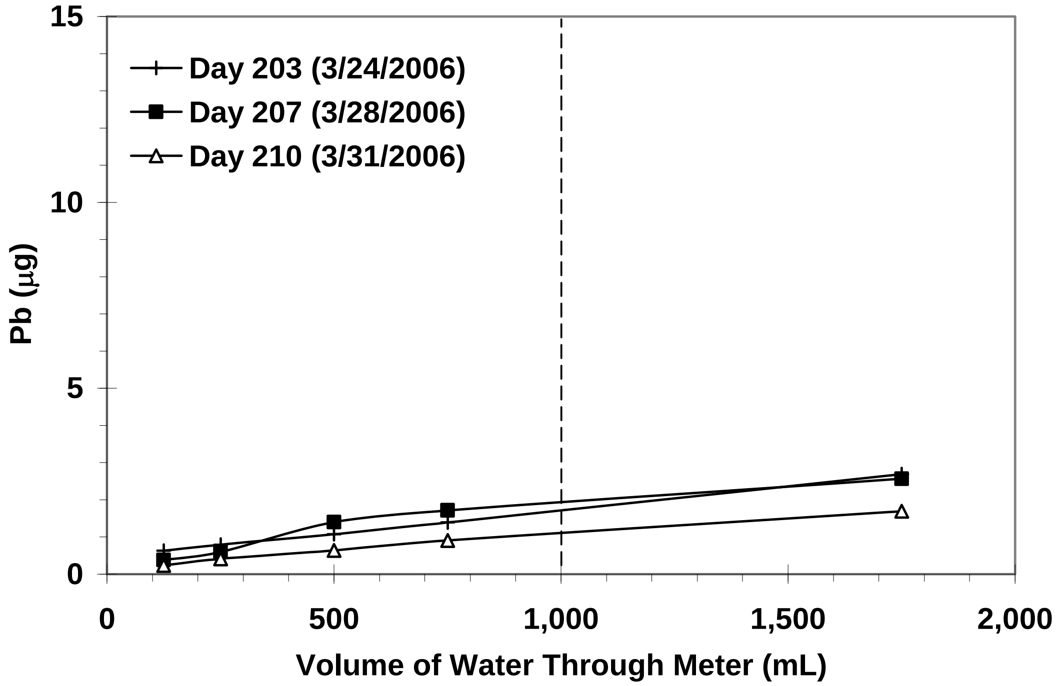


Figure C.57 Cumulative total Pb mass in Meter 4 – 40 years old (6-hour stagnation samples from simulated use at 4 L/min).

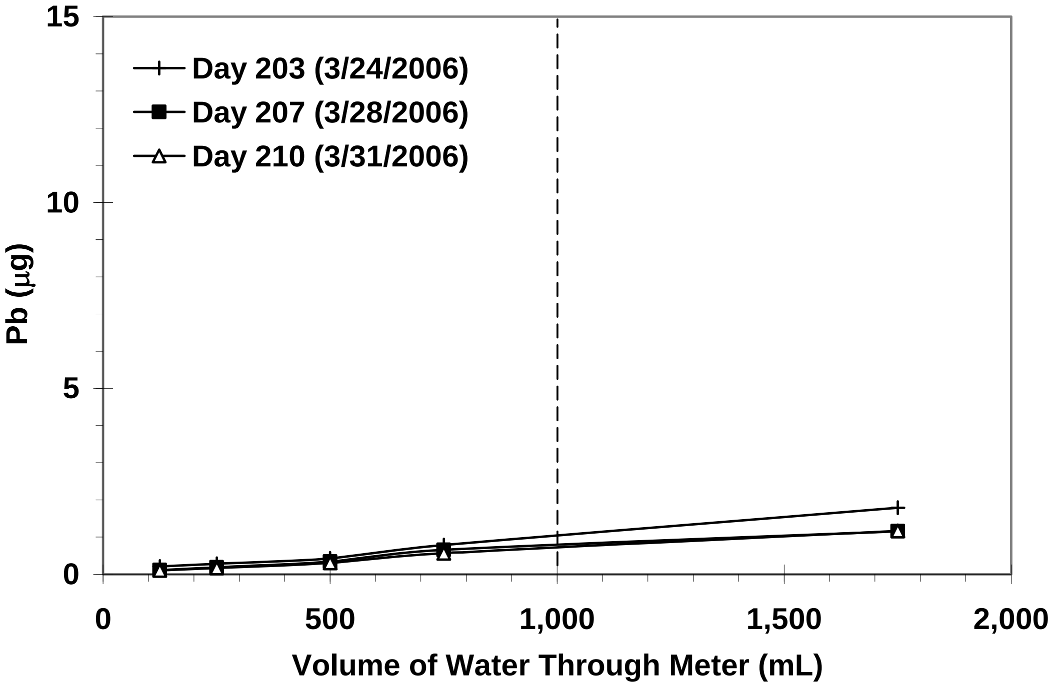


Figure C.58 Cumulative total Pb mass in Meter 5 – new Envirobrass (6-hour stagnation samples from simulated use at 4 L/min).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

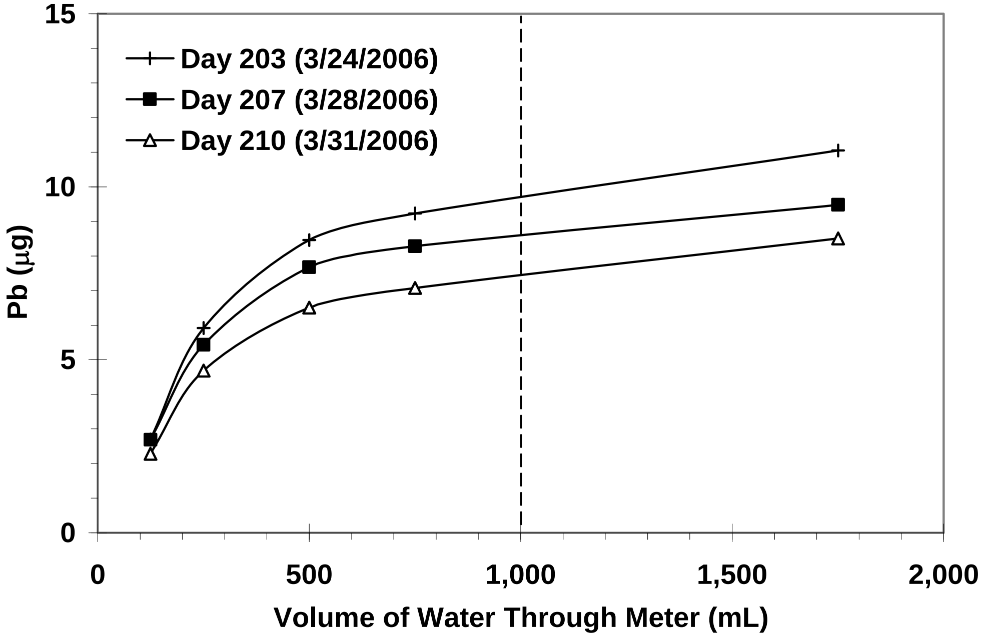


Figure C.59 Cumulative total Pb mass in Meter 6 – new leaded brass (6-hour stagnation samples from simulated use at 4 L/min).

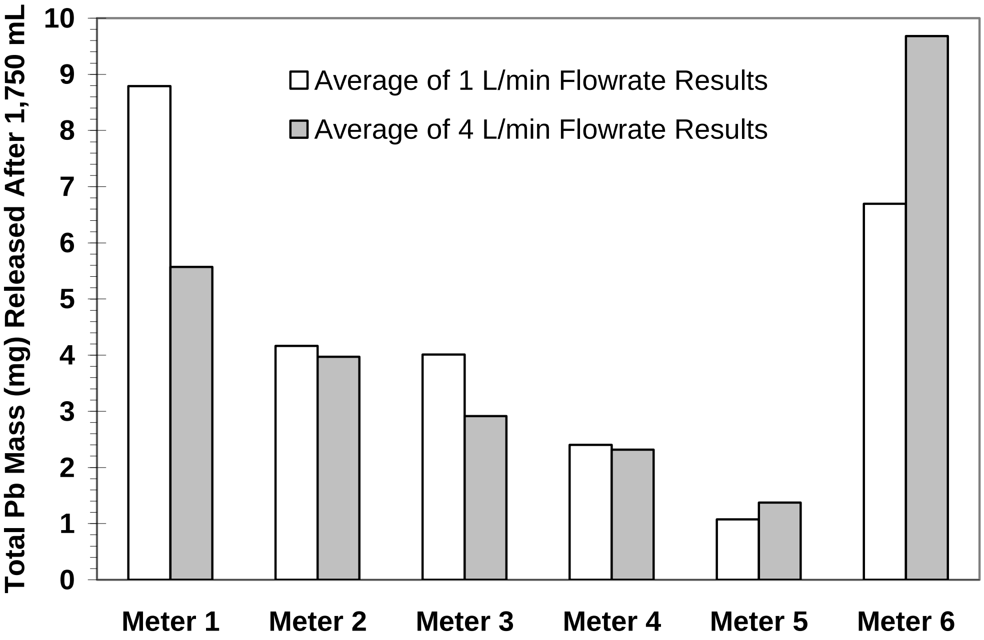


Figure C.60 Comparison of total Pb mass released after 1,750 mL between 1 L/min and 4 L/min.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Figure C.61 shows that the amount of dissolved Pb for the testing at 4 L/min was generally the same though the total Pb mass released decreased somewhat in the first 125 mL sample – which means that particulate Pb decreased. These results help support the hypothesis that the scales on the older meters' interiors are strongly adhered to the metal surface and are resistant to the higher velocity-induced scouring. For Meter 6, the new brass meter, these results are less conclusive, though when reviewed in conjunction with the time-series data shown in Figure C.59, could indicate that the interior scales are continuing to form.

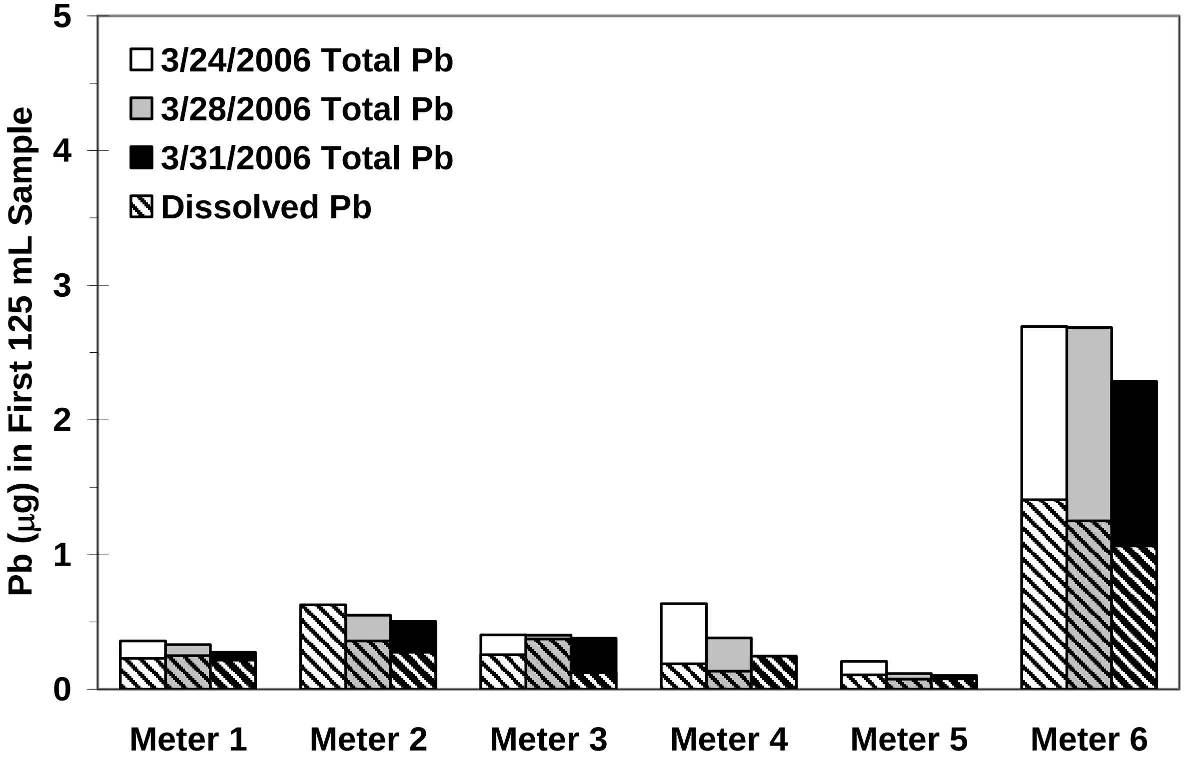


Figure C.61 Comparison of total and dissolved Pb in first 125 mL sample from each meter (6-hour stagnation samples from simulated use at 4 L/min).

Analyzing for Cu found that there was no appreciable change in the release of the metal from any of the meters when the Cedar tap water flow rate increased. Again, Meter 6 had the highest Cu release (see Figure C.62), which is still well below the AL.

Se and Bi exhibited opposite behavior for Meter 5 at the higher flowrate. Se release was found to nearly double at 4 L/min. (Figure C.63). In comparison, Figure C.64 shows that Bi release was nearly halved. However, Se was found to be nearly all in the particulate form while Bi had nearly the same dissolved-to-particulate proportions. There is no explanation for why the total release of these two trace elements exhibited opposite behavior in response to the increased flowrate. Se and Bi release from the other meters were again at or below the MRL.

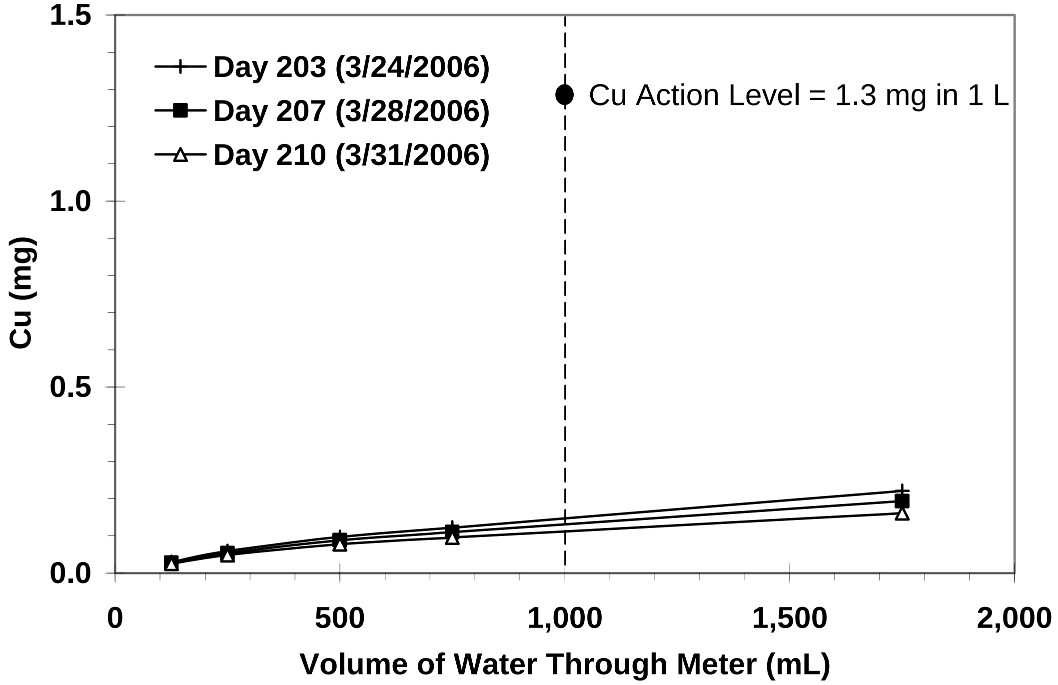


Figure C.62 Cumulative total Cu mass in Meter 6 – new leaded brass (6-hour stagnation samples from simulated use at 4 L/min).

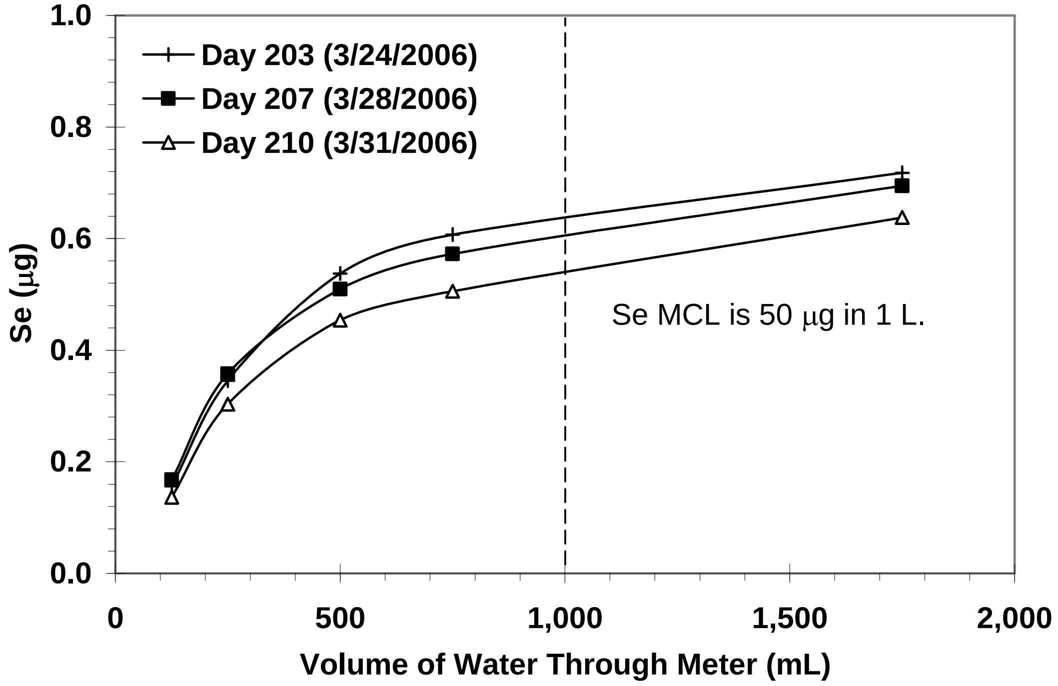


Figure C.63 Cumulative total Se mass in Meter 5 – new Envirobrass (6-hour stagnation samples from simulated use at 4 L/min).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

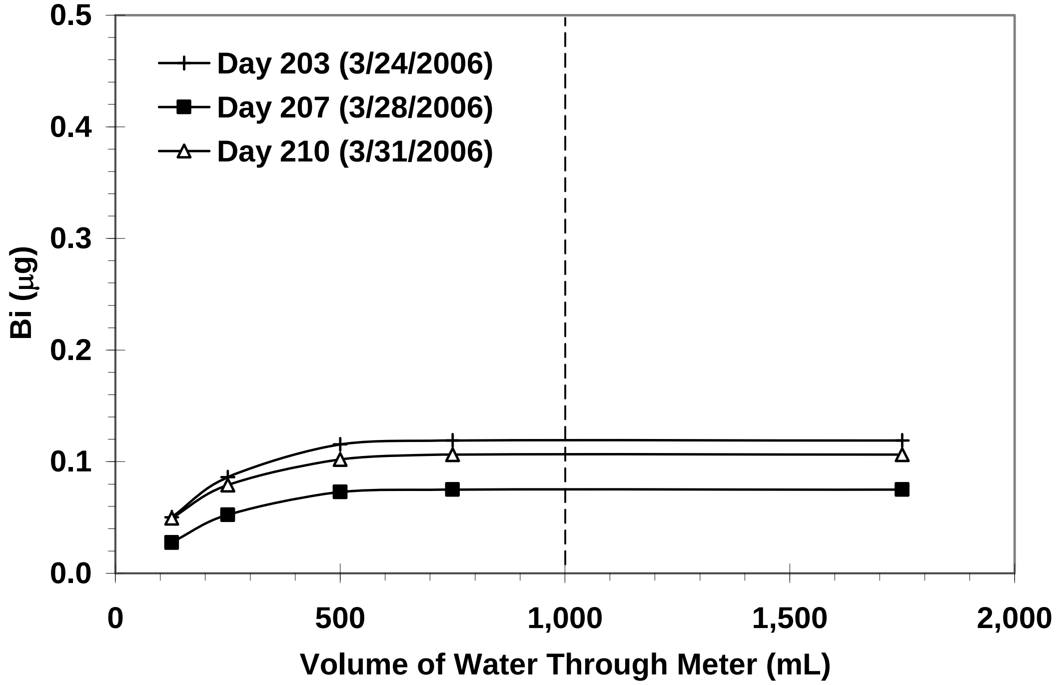


Figure C.64 Cumulative total Bi mass in Meter 5 – new Envirobrass (6-hour stagnation samples from simulated use at 4 L/min).

Impact of Stagnation Durations

This experiment was conducted using 1-L samples drawn from each meter at different stagnation times ranging from 30 minutes to 20 hours. This experiment was conducted from March 1, 2006 to March 3, 2006 (Days 180 to 182 of use), between the low-flow and high-flow evaluations. Figure C.65 shows how Pb concentrations varied over this time frame. In general, the trend for each meter showed a logarithmic increase in Pb release over time. A second trend was that the Pb concentration at each time step decreased with brass meter age. The new brass meter had the highest detected Pb, the used Meters 1, 2, and 3 had somewhat similar results, and the oldest meter had relatively low Pb readings. Once again, the Envirobrass meter had the smallest concentrations of Pb detected. The 20-hour result for Meter 1 did not follow the general trend developed with the other results for the meter or the trends for the other 5 meters. As such, the data point was believed to be erroneous and was not included in the trend line shown in the figure.

While Cu release was found to increase with correspondingly longer stagnation times, there was no discernable correlation between Cu release with meter age or material. Figure C.66 shows that unlike all the previous tests that found Cu release to be highest with a new brass meter, this experiment determined that two of the older meters and the Envirobrass one all released more Cu. It is unclear why this change in release patterns occurred though it must be noted that the maximum Cu release when using the SPU tap water was still less than a quarter of the AL at even the longest stagnation time.

Se release over time is shown in Figure C.67. The results show that the new Envirobrass meter had the most Se release over the stagnation periods though even that was significantly below the 50 µg/L MCL. There was a consistent analytical issue during this experiment that prevented Bi from being correctly analyzed. As result, there are no results to present. However, given the data presented previously, the researchers believe that Bi would be present only in the new Envirobrass meter and the amount released would be less than 1 µg/L.

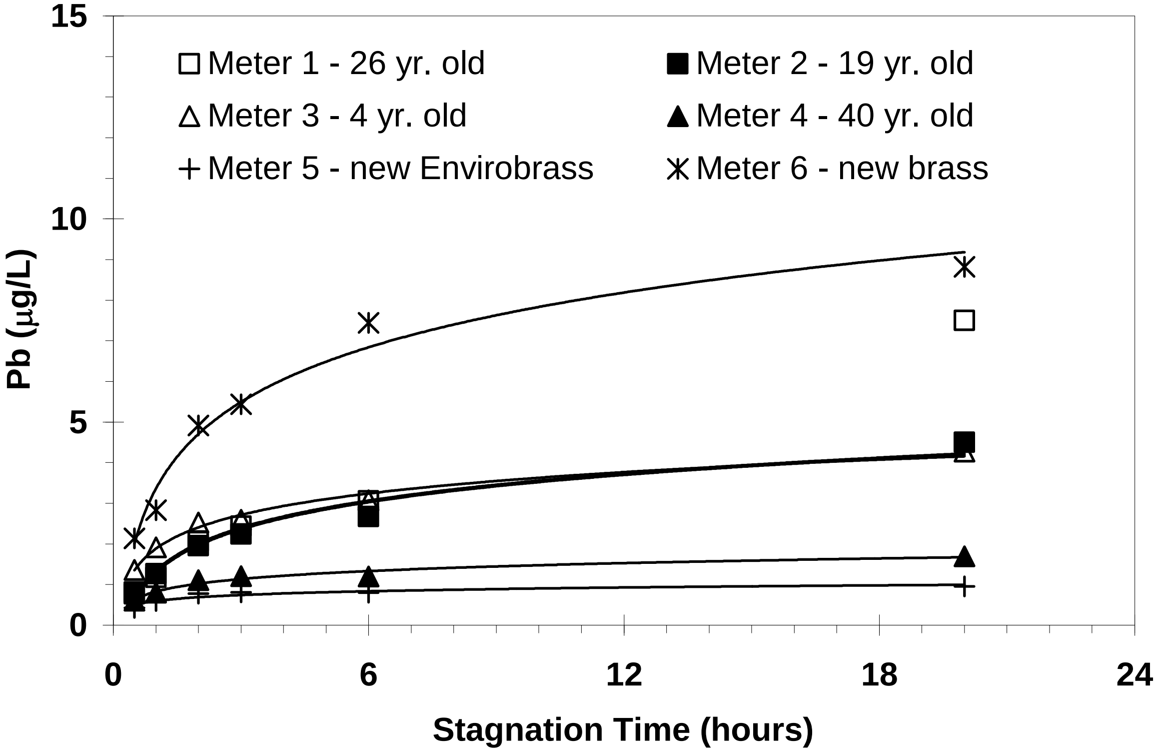


Figure C.65 Total Pb concentrations in 1-L samples with varying stagnation times conducted on Days 180 through 182. Trend line for Meter 1 excludes 20-hour sample data.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

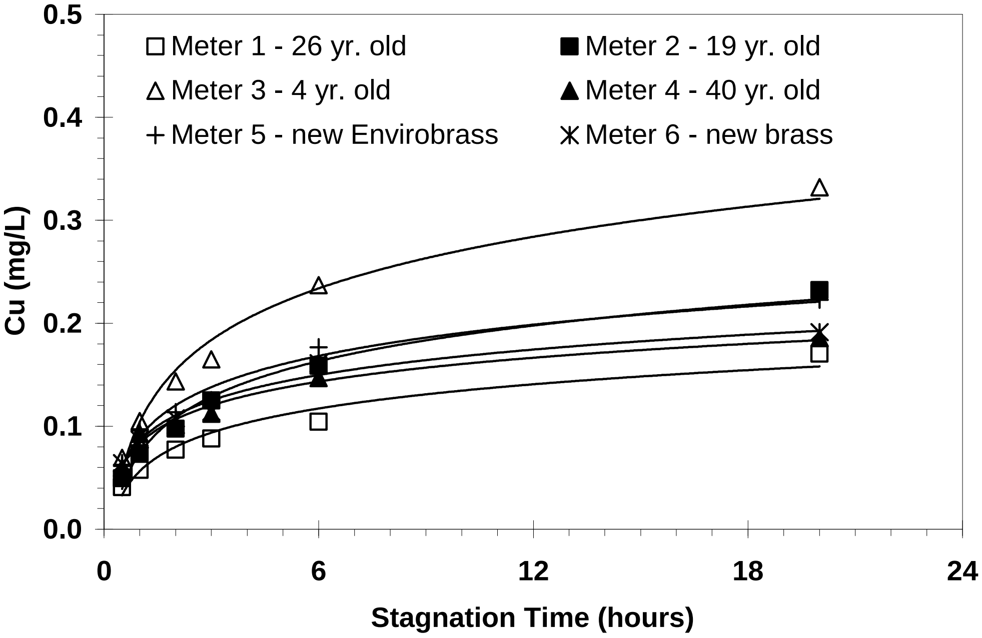


Figure C.66 Total Cu concentrations in 1-L samples with varying stagnation times conducted on Days 180 through 182.

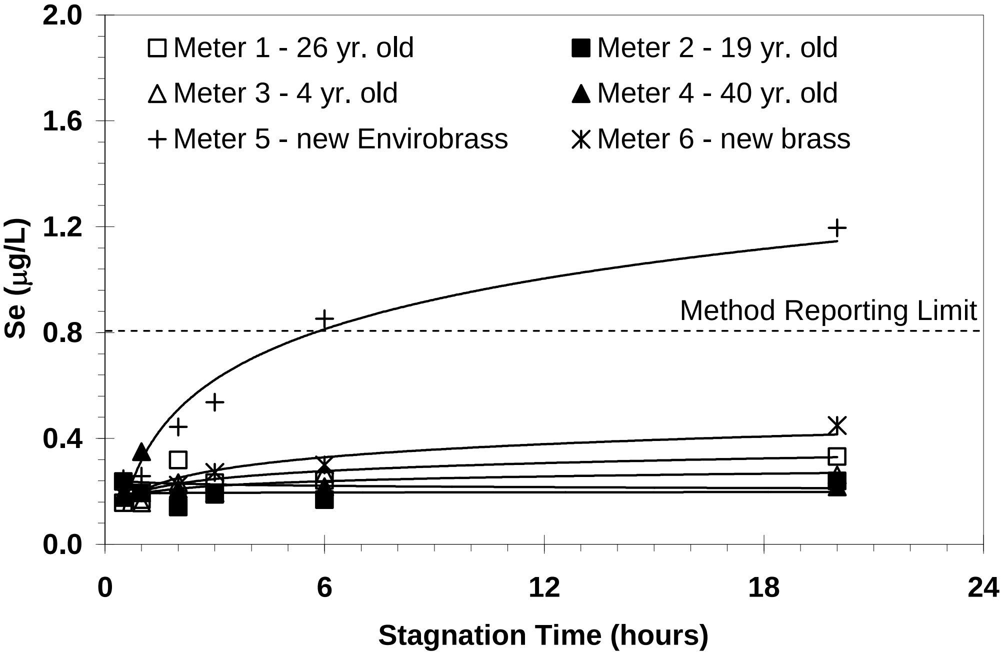


Figure C.67 Total Se concentrations in 1-L samples with varying stagnation times conducted on Days 180 through 182.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scale Analyses

Six residential water meters were used in side-by-side testing to identify their potential lead (Pb) and copper (Cu) contributions to water in first-draw stagnation samples. The meters ranged in service age from new, never used units to one that had been in service for 40 continuous years. Five of the meters were brass with up to 8% Pb content, and one was the new “no-lead” brass in which the Pb content is less than 0.2%, and bismuth (Bi) and selenium (Se) (a regulated element) are used in its place (Table C.17). A seventh meter, which was not used in the rig, was tested as received out of the box.

Table C.17
Metal contents of meters determined before insertion in rack

			Metals Concentration							
Meter #	**Manufacturer**	**Age of Meter**	**% Pb**	**% Cu**	**%Zn**	**%Se**	**%Sb**	**%Bi**	**%Fe**	**Zn/Cu**
1	A	26 yr. Old	4.97	83.64	4.52	0.037	0.064	0.000	0.131	0.0540
2	B	19 yr. Old	6.83	80.12	7.91	0.000	0.081	0.000	0.178	0.0987
3	B	4 yr. Old	7.01	80.86	8.77	0.000	0.035	0.000	0.195	0.1084
4	C	40 yr. Old	6.45	79.42	9.60	0.000	0.000	0.000	0.096	0.1208
5	D	New	0.03	90.01	5.69	0.325	0.000	1.726	0.000	0.0632
6	B	New	6.65	78.97	8.19	0.000	0.000	0.086	0.221	0.1038
7	B	New	6.65	78.97	8.19	0.000	0.000	0.086	0.221	0.1038

Input water quality

The meter rig used water from Seattle’s Cedar supply. Input parameters for the rig are shown in Table C.18, based on laboratory measurement of the water coming in to the rig for pH, alkalinity, temperature, lead, copper, and selenium. Other parameters are from the utility’s 2005 water quality reports.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table C.18
Water quality of input water for Seattle meter rig

Parameter	Result	Standard units
pH	8.24	
Temperature	10.9	Degrees C
Alkalinity	21.7	mg/l as CaCO3
Chloride	4.7	mg/l
Sulfate	1.4	mg/l
Fluoride	0.95	mg/l
Phosphate	0.004	mg/l
Nitrate	0.055	mg/l
Sodium	2.76	mg/l
Potassium	0.27	mg/l
Magnesium	1.11	mg/l
Calcium	10.08	mg/l
Iron	0.036	mg/l
Manganese	0.004	mg/l
Lead	0.00049	mg/l
Copper	0.0322	mg/l
Selenium	0.00011	mg/l

These data can be used to predict what scale minerals are likely to form in the Seattle distribution system. Using the PHREEQC model from the US Geological Survey with the MINTEQ database option (Table C.19), none of the common Pb minerals is stable under current conditions. Cerussite, common as a scale mineral in other systems, is significantly undersaturated, and the distribution water can be expected to be aggressive to any pre-existing Pb carbonates. Several Fe and Mn oxide minerals are supersaturated, as is the Cu oxide tenorite and the carbonate malachite. These minerals are likely to be important components in scales forming today. The Al hydroxide gibbsite is slightly supersaturated, and could precipitate.

Meter #1.

Meter 1 had been in service for 26 years. Its metal content is 5 % Pb with a Zn/Cu ratio of 0.054. Visually, it is coated with a thin, even film of a white scale with some brown patches (Figure C.68).

Table C.19
Saturation states from PHREEQC speciation model using Minteq database

Mineral	Formula	Saturation Index
Cerussite	$PbCO_3$	-2.04
Gibbsite	$AlOH_3$	0.53
Goethite	FeOOH	5.42
Hydroxylapatite	$Ca_5(PO_4)_3OH$	0.38
Malachite	$Cu_2(OH)_2CO_3$	1.64
Manganite	MnOOH	1.21
Pyromorphite	$Pb_5(PO_4)_3Cl$	-2.13
Tenorite	CuO	0.69

The saturation index is the log of the ratio of measured concentrations to equilibrium concentrations. A negative value indicates water compositions undersaturated with the mineral

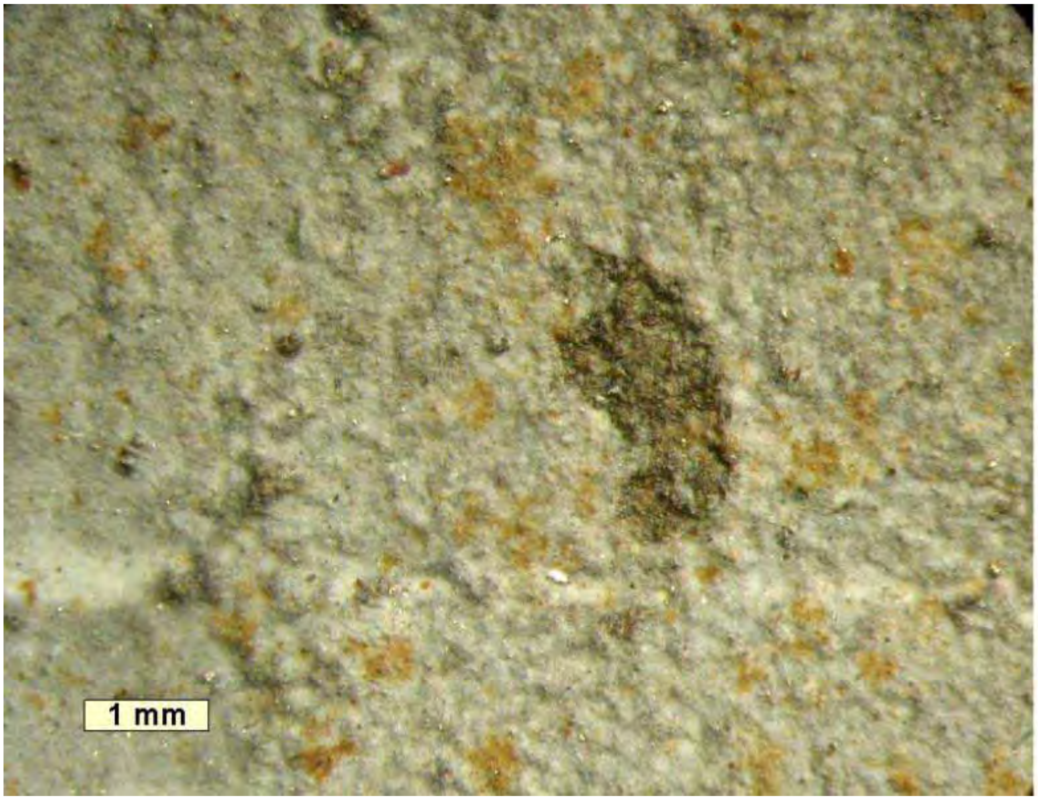


Figure C.68 Photomicrograph of bottom of meter #1.

In SEM, the scale is seen to consist of Cu oxide with minor Fe oxide, but with abundant siliceous skeletons of diatoms (Figure C.69). EDS indicates about 2 % Fe and 6 % Si in addition to Cu and Pb.

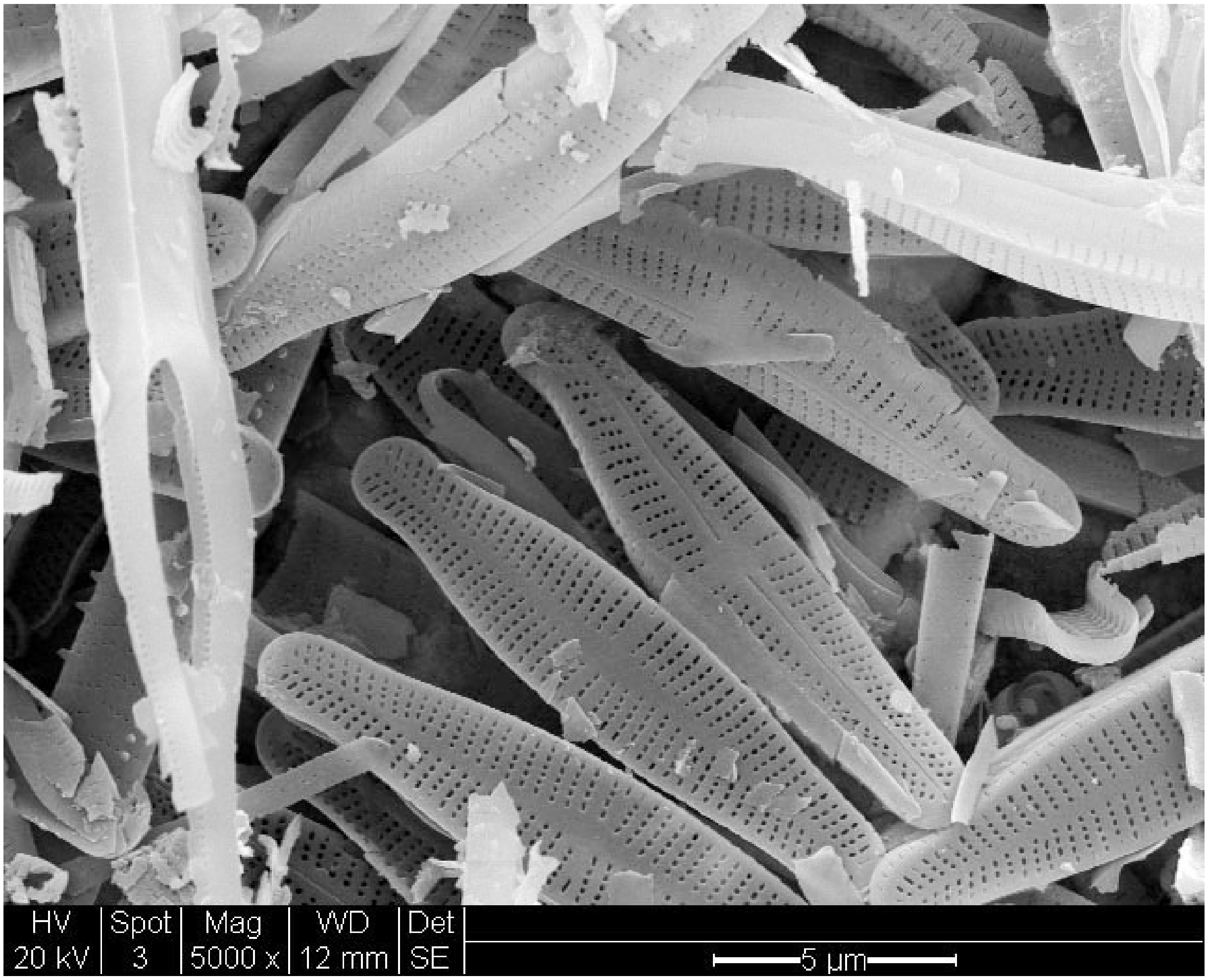


Figure C.69 SEM image of bottom of meter #1. The particles are skeletons of diatoms that have been incorporated in the scale.

After 20 hours of stagnation, meter 1 had released about 170 µg/l of Cu, 28 µg/l of Zn and 7.5 µg/l of Pb. Release kinetics were calculated using a power function as shown in Figure C.70. The Zn release rate is faster than the Cu release rate, indicating preferential dezincification of the brass.

Meter #2

Meter 2 had been in service for 19 years. Its metal content is 6.8 % Pb with a Zn/Cu ratio of 0.099. Visually, it has a thin, patchy film of white scale with large areas of brass showing through (Figure C.71).

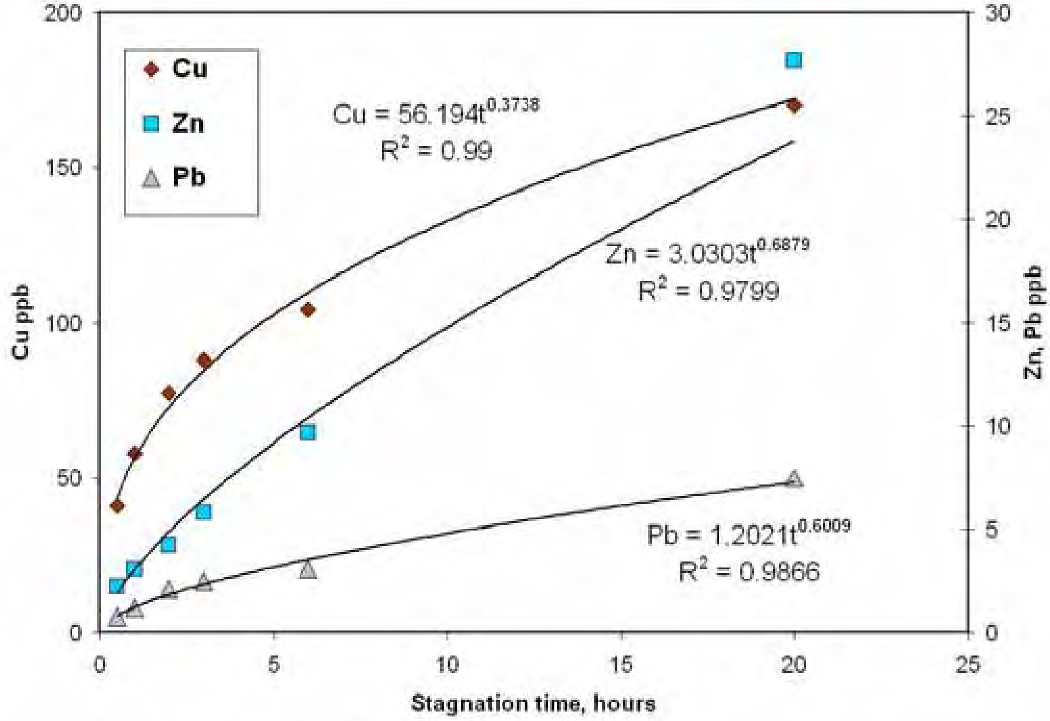


Figure C.70 Metal release kinetics for meter 1. Note different scales for Cu and for Zn or Pb.

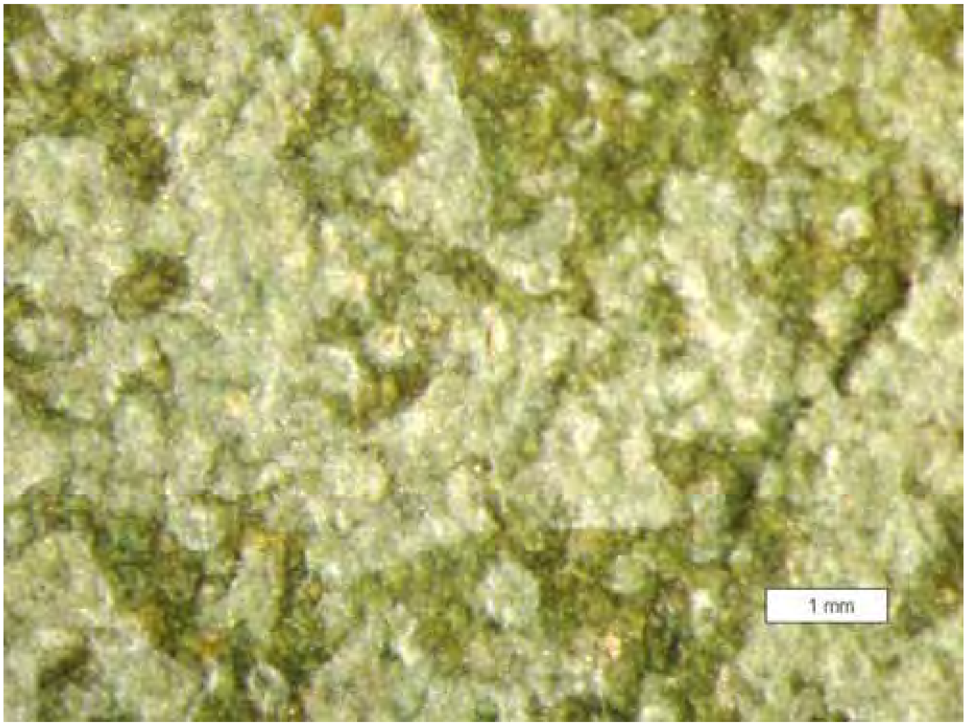


Figure C.71 Photomicrograph of bottom of meter 2.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

SEM analysis indicates that this scale is a mixture of Pb and Cu oxides with minor Fe oxide. Pb content is between 20 and 30 %. Fe and Mn are in the 1 to 2 % range.

Metal release kinetics for meter 2 are similar in form to meter 1, but Pb release is somewhat slower, as shown in Figure C.72. Cu and Zn release rates are similar to each other, but note that the Zn curve is slightly steeper than the Cu curve at the end of the experiment, again consistent with dezincification of the brass.

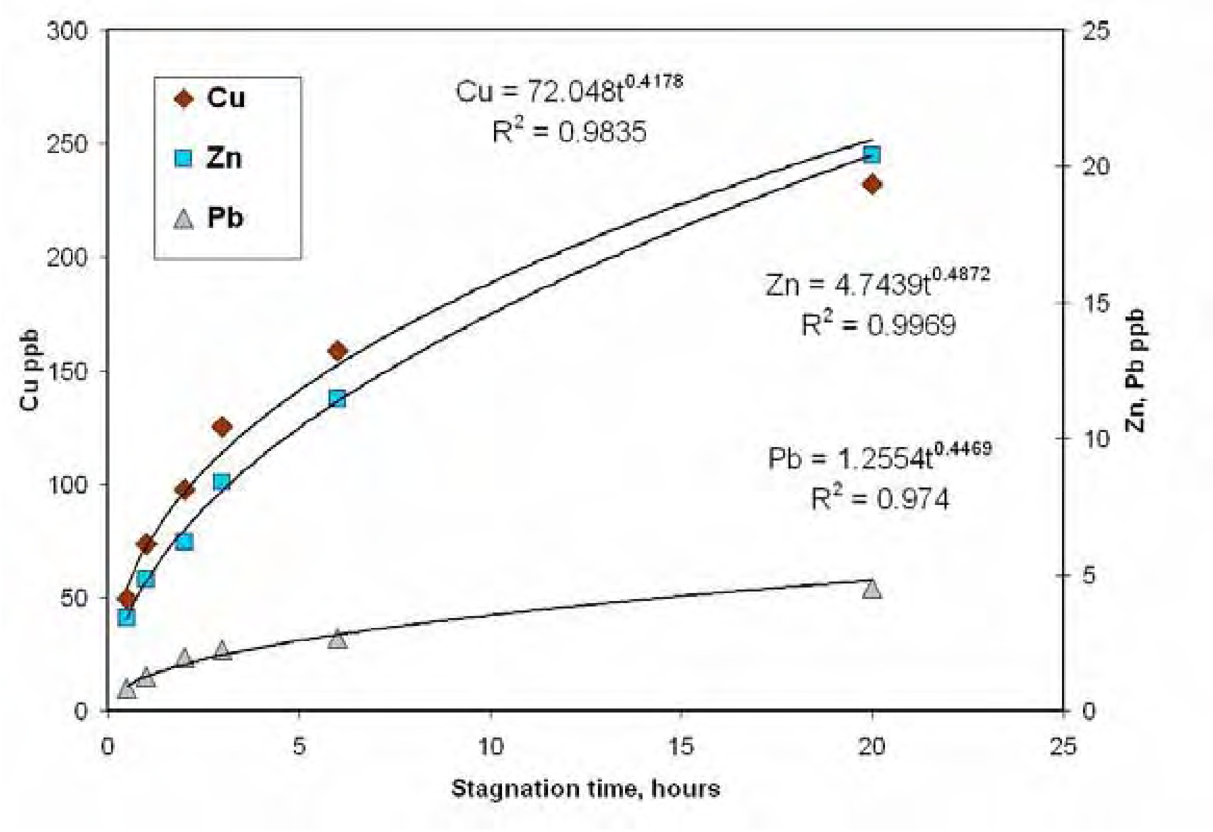


Figure C.72 Metal release kinetics for meter 2. Note different scales for Cu and for Zn or Pb.

Meter #3

Meter 3 had been in service for 4 years. Its metal content is 7 % Pb with a Zn/Cu ratio of 0.11. Visually, it has a few areas with patchy green and white scale (Figure C.73). These are best developed in sheltered areas away from the rotor.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

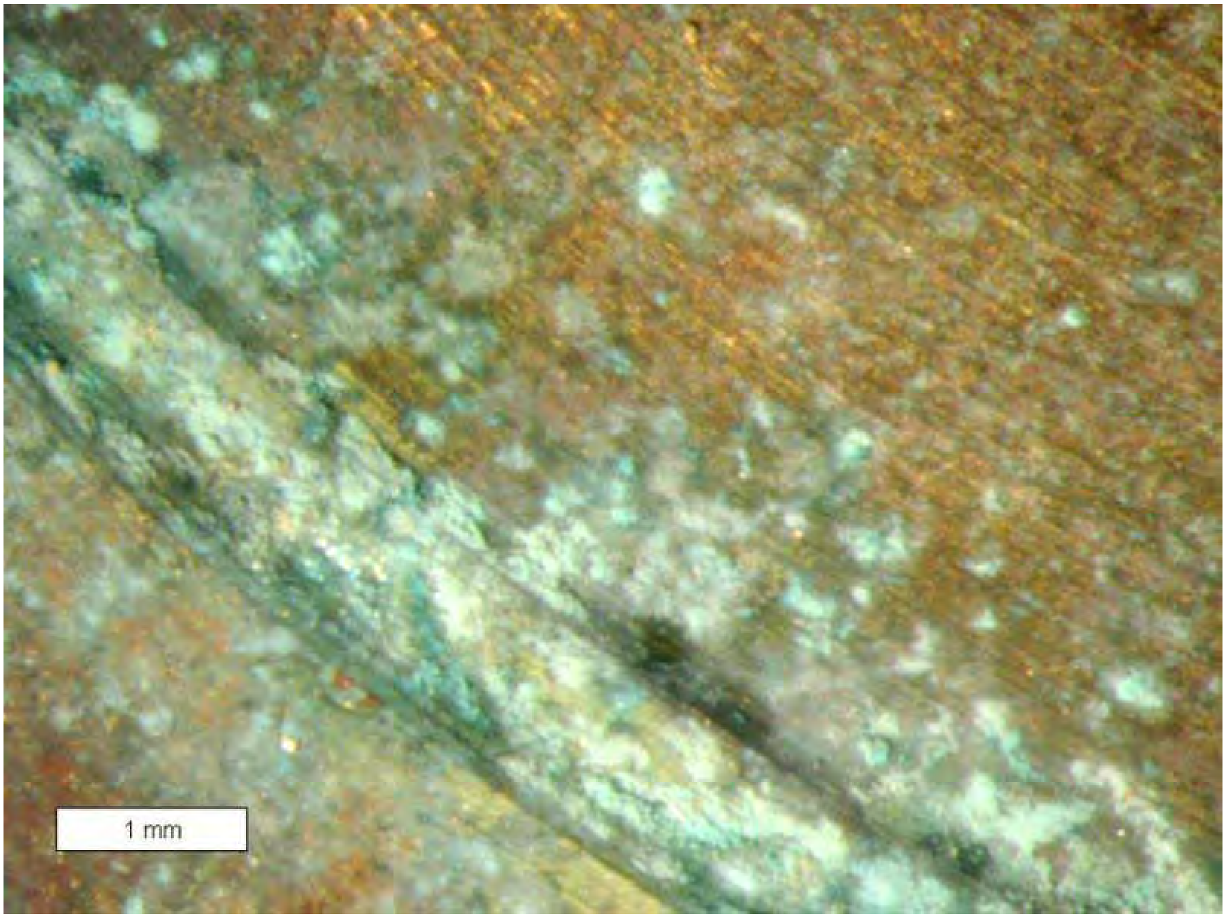


Figure C.73 Photomicrograph of bottom of meter 3.

SEM analysis shows this material to be Cu oxide and carbonate that contains 15 to 30 % Pb. Fe and Mn are less than 1%.

Metal release kinetics for Pb were somewhat slower than for meters 1 and 2 (Figure C.74). Cu and Zn rates are similar to each other, but Zn is being leached faster than Cu at the end of the experiment.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

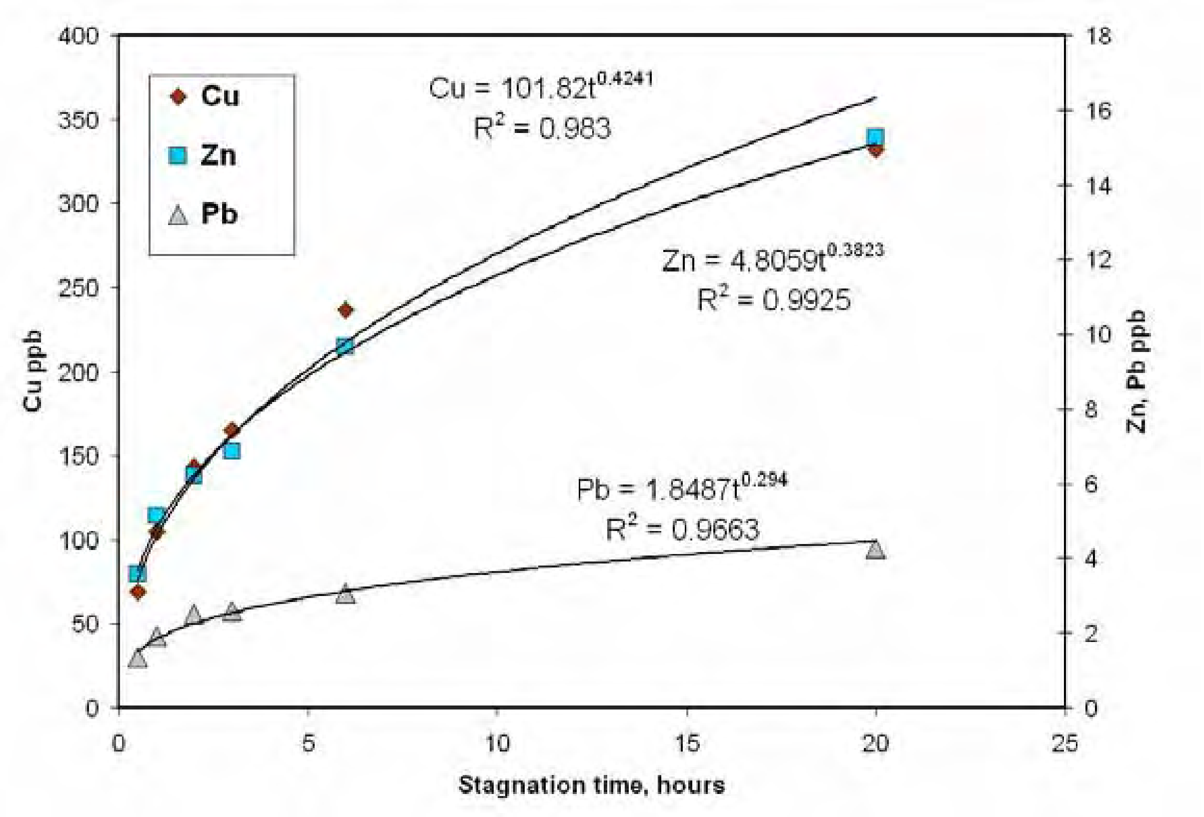


Figure C.74 Metal release kinetics for meter 3. Note different scales for Cu and for Zn or Pb.

Meter #4

Meter 4 had been in service for 40 years. Its metal content is 6.5 % Pb with a Zn/Cu ratio of 0.12, the highest among the meters tested. Visually, it has extensive areas of thin brown scale with smaller patches of green and white scale (Figure C.75).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

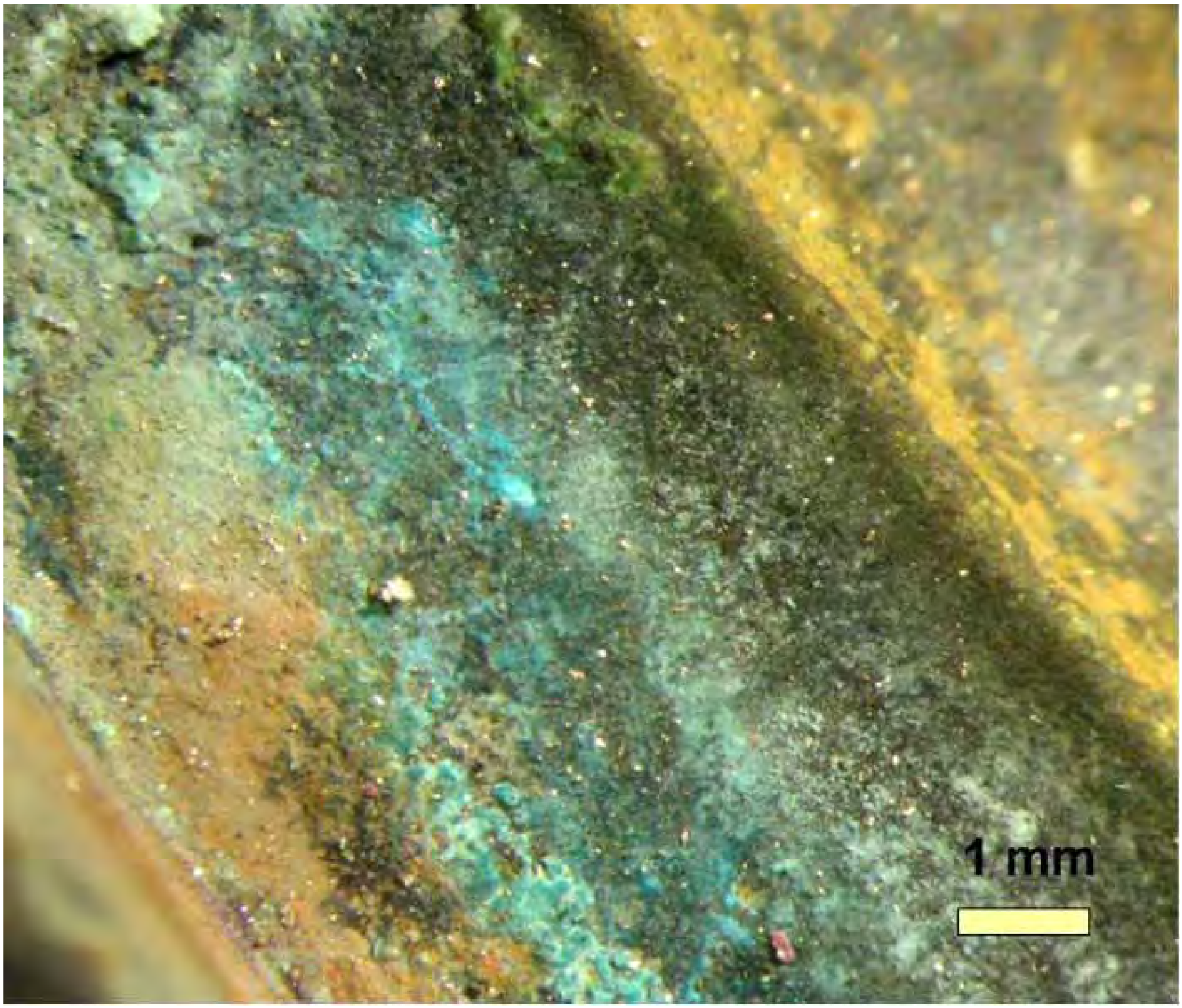


Figure C.75 Photomicrograph of the bottom of meter 4, showing the green scale. Brown scale is a really more extensive.

In the SEM, the scale shows an even, granular appearance (Figure C.76). EDS analysis indicates about 10 % Pb and 10 % Fe, the Fe most likely as an oxide. Copper in the scale appears to be present as both the oxide and the carbonate.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

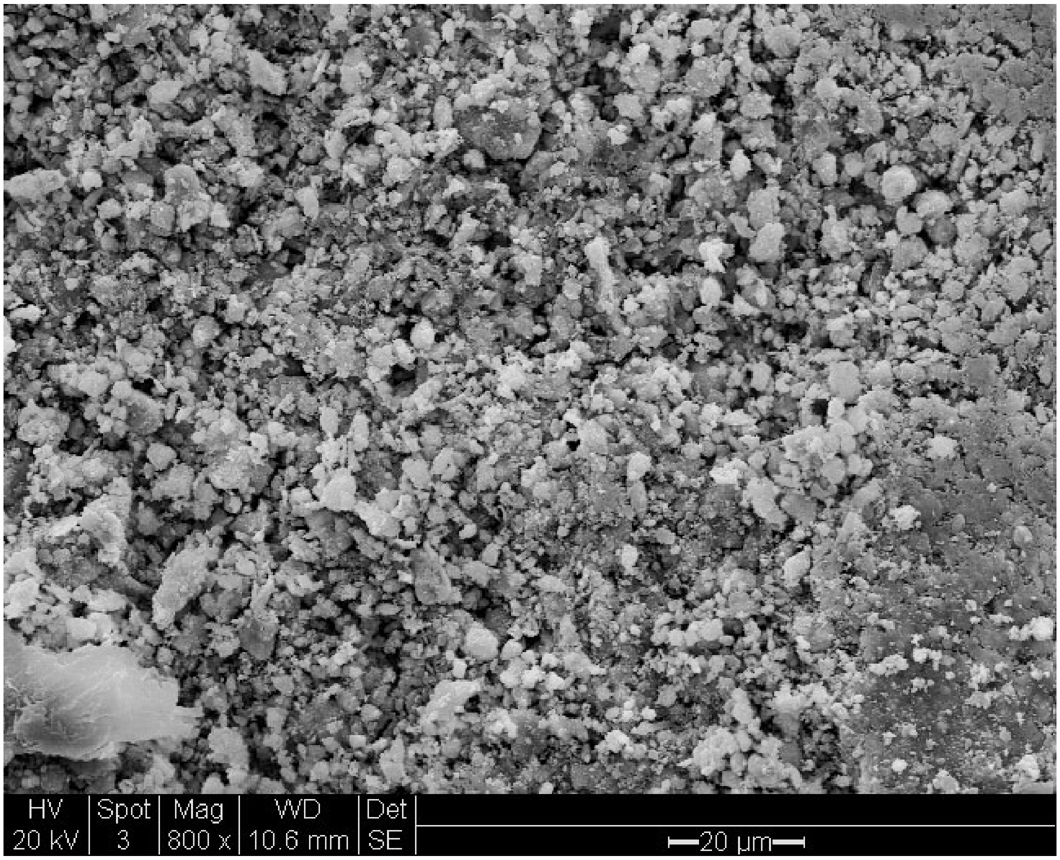


Figure C.76 SEM image of scale from the bottom of meter 4. Particles are about a micron across.

Metal release kinetics for meter 4 show considerably lower Pb release than for the previous meters (Figure C.77). Cu and Zn release rate constants are essentially identical, indicating that preferential dezincification is no longer an important process for this brass.

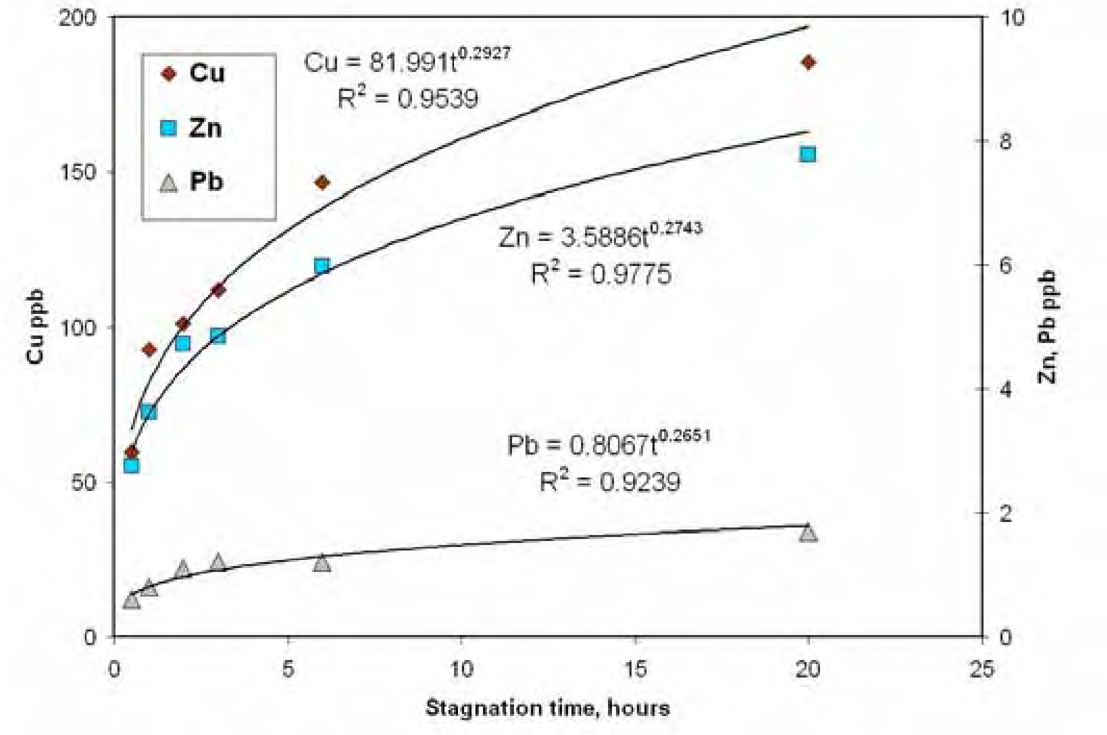


Figure C.77 Metal release kinetics for meter 4. Note different scales for Cu and for Zn, Pb.

Meter #5

Meter 5 was a new meter constructed of non-leaded brass, an alloy in which bismuth replaces lead. This meter showed no visible corrosion (Figure C.78).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Figure C.78 Photograph of the bottom of meter 5.

Metal release kinetics for meter 5 (Figure C.79) follow a similar pathway to that seen in the other meters. Only limited amounts of Pb appear (up to 0.95 µg/l), as expected, but the Cu and Zn releases follow the power function seen for the other meters. There are also minor amounts of Bi released (up to 0.25 µg/l). Zn release is significantly faster than Cu release, so the envirobrass, like more traditional brasses, is undergoing dezincification.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

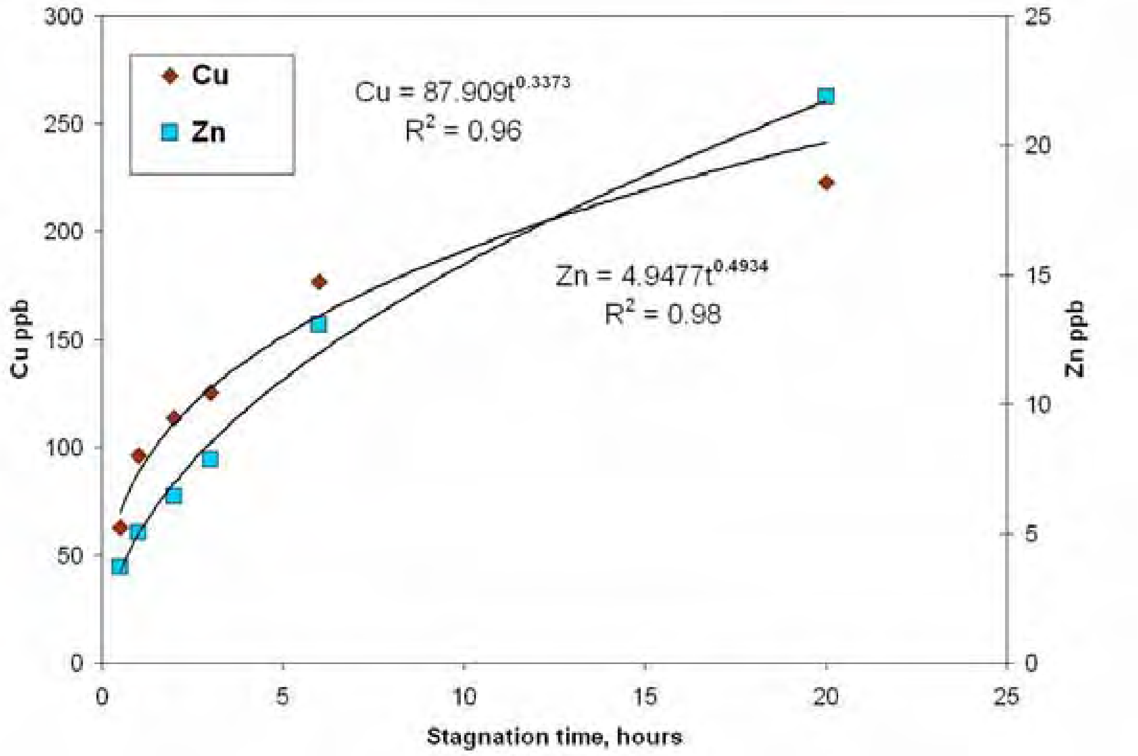


Figure C.79 Metal release kinetics for meter 5. Note different scales for Cu and for Zn.

Meter #6

Meter 6 was a new meter with 6.7 % Pb and a Zn/Cu ratio of 0.103. This meter showed white corrosion deposits at various points on the meter bottom (Figure C.80). SEM analysis indicates a Pb carbonate, most likely hydrocerussite (Figure C.81). Results from meter 7 (see below) suggest that this scale may have been present in the meter before it was placed in the rig. In addition to Pb, the scale only has small amounts of Cu. The Fe and Mn seen in older meters are lacking.

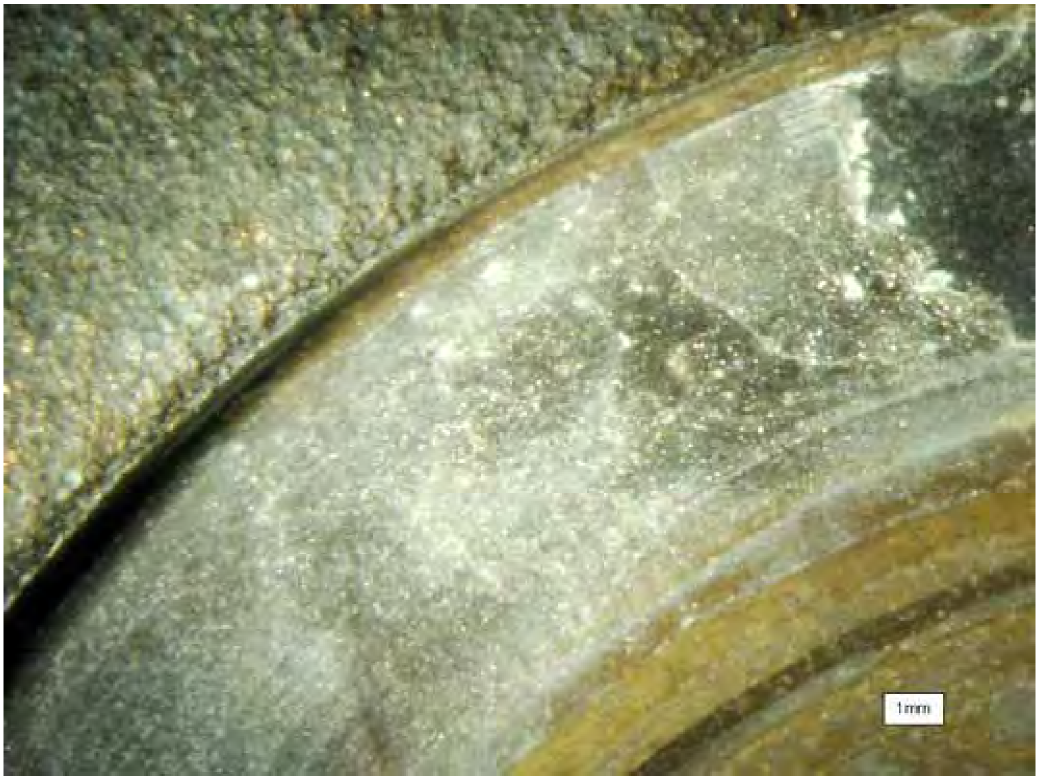


Figure C.80 Photograph of the bottom of meter 6.

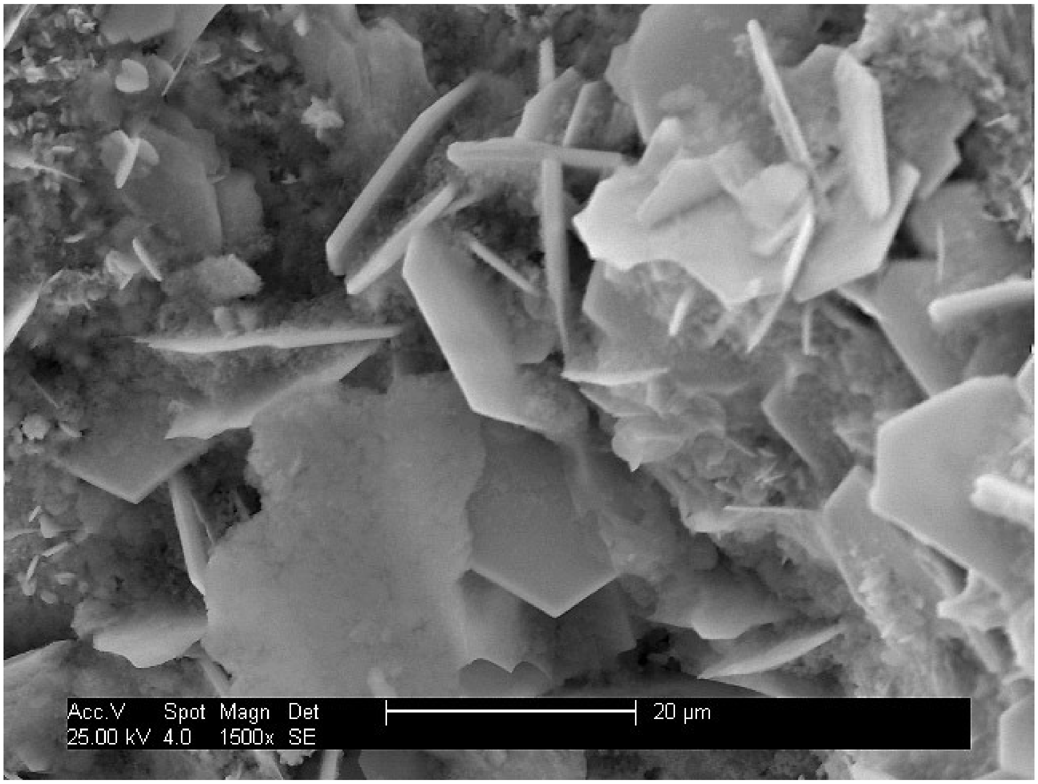


Figure C.81 SEM image of Pb carbonate scale from meter 6.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Metal release kinetics for meter 6 (Figure C.82) show Zn release to be significantly faster than Cu release, so that dezincification is more intense in the newer meters. This meter had the highest Pb concentration after 20 hr stagnation. Based on PHREEQC models, some of this Pb may come from dissolution of Pb carbonate rather than from leaching of Pb from the brass itself.

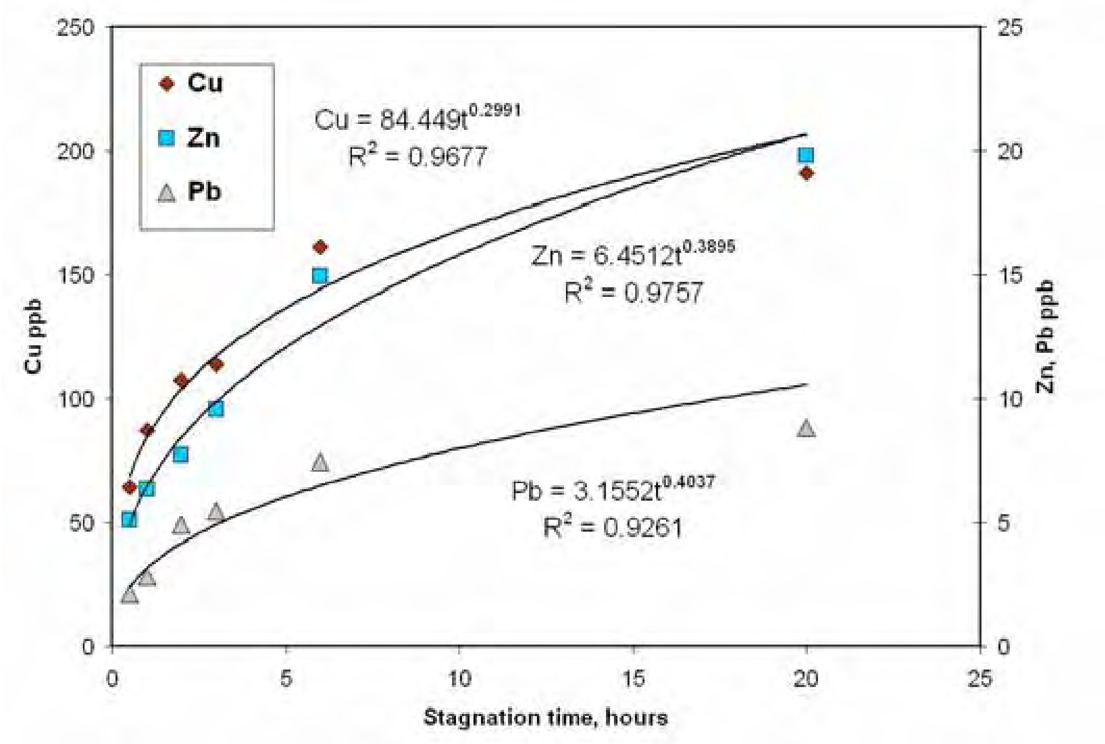


Figure C.82 Metal release kinetics for meter 6. Note different scales for Cu and for Zn, Pb.

Meter #7

The bottom of meter 7, which was never mounted in the rig and thus serves as a blank, has patches of white scale (Figure C.83). In the SEM, these patches are seen to be lead carbonate, probably hydrocerussite (Figure C.84).

Figure C.83 Photograph of the bottom of meter 7.

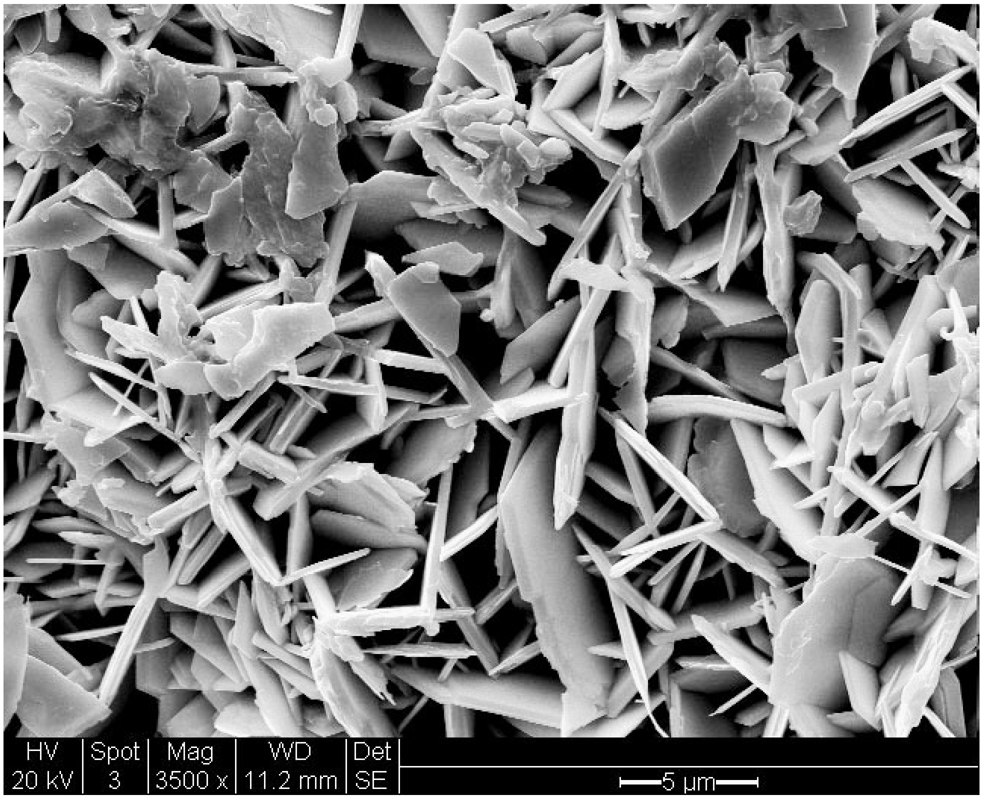


Figure C.84 SEM image of Pb carbonate scale from meter 7.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

The presence of Pb carbonate scale in the blank means that the degree of scale development in the meters is not a useful parameter. The chemical conditions under which these scales developed is unknown. However, the undersaturation of the Seattle Cedar supply with respect to both Pb the carbonates (cerussite and hydrocerussite) suggests that these scales will dissolve once the meter is in service and could provide an extra source of Pb.

Kinetics of Reaction

The reaction progress for each meter can be modeled effectively with a power function. That is the kinetics are of the form

$$y = At^k$$

where k is the exponential factor, A is the pre-exponential factor, and t is the time. Many corrosion reactions of metals have diffusion as the rate limiting step, in which case k = 0.5. In Table C.20, the rate constants for each metal are shown. Many, but not all of the exponential factors are close to this value and are thus consistent with diffusion of Zn from the matrix of the brass or through an overlying scale.

Table C.20
Rate constants for leaching of brass meters during stagnation

Meter	Age	A_{Cu}	k_{Cu}	A_{Zn}	k_{Zn}	A_{Pb}	k_{Pb}	Zn/Cu
	years	pre-exp	exp	pre-exp	exp	pre-exp	exp	brass
5*	0	87.9	0.337	4.95	0.493	0.58	0.199	0.0632
6	0	84.5	0.299	6.45	0.390	3.15	0.404	0.1038
3	4	101.8	0.424	4.81	0.383	1.85	0.294	0.1084
2	19	72.1	0.418	4.74	0.488	1.26	0.449	0.0987
1	26	56.2	0.374	3.03	0.688	0.12	0.601	0.0540
4	40	82.0	0.293	3.54	0.274	0.81	0.250	0.1208
Average brass		79.3	0.362	4.514	0.4446	1.437	0.400	0.0971

**Meter 5 is envirobrass*

The exponential factor in the rate expression for Zn release is strongly a function of Zn/Cu ratio (Figure C.85). The higher the Zn content, the slower the leaching rate of Zn from the brass. The Pb exponential factor closely follows that of Zn, but Cu does not. The average value of the exponential factor, about 0.4 for both Zn and Pb, suggests that diffusion is the dominant control on leaching rates. The variation with Zn content could perhaps be related to increased porosity formation in the low-Zn brasses.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

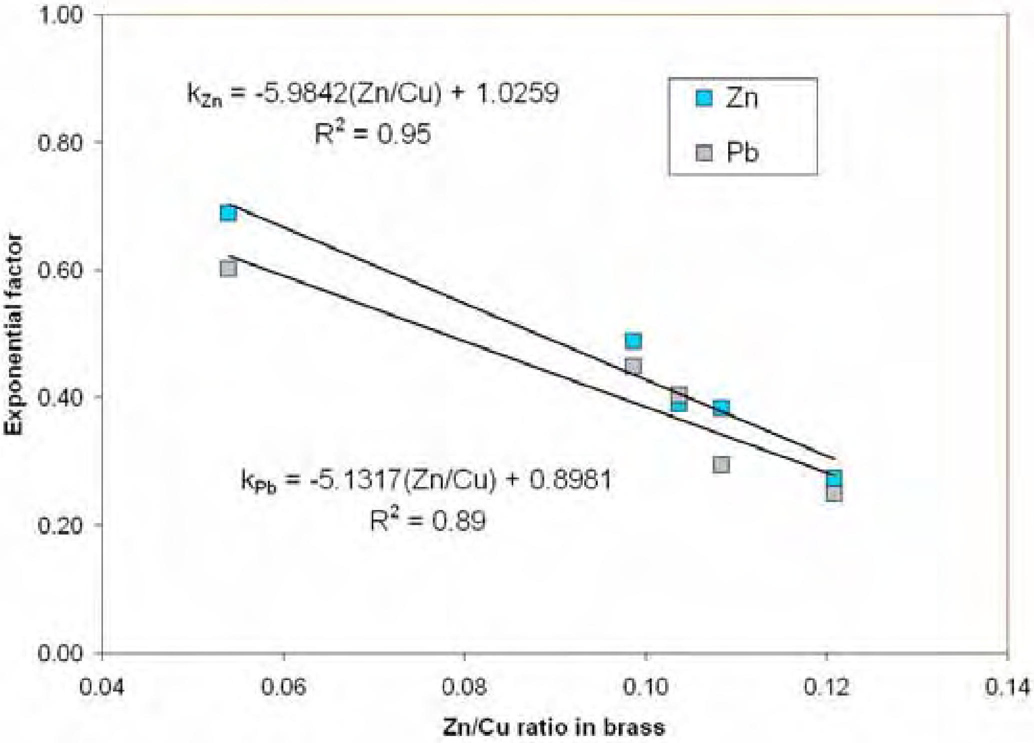


Figure C.85 The rates of Zn and Pb release, as measured by the exponential factor, as a function of Zn content of the brass.

By contrast, the pre-exponential factor is related to the age of the meter (Figure C.86). That is, the newer meters have a larger pre-exponential factor and hence leach Zn and Pb faster than the older meters. Again, Pb rates follow the same relationship as Zn rates, but in this case with a lower intercept at t = 0. A reasonable interpretation of this relationship is that age is a proxy for the extent and thickness of passivating Cu oxide scale

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

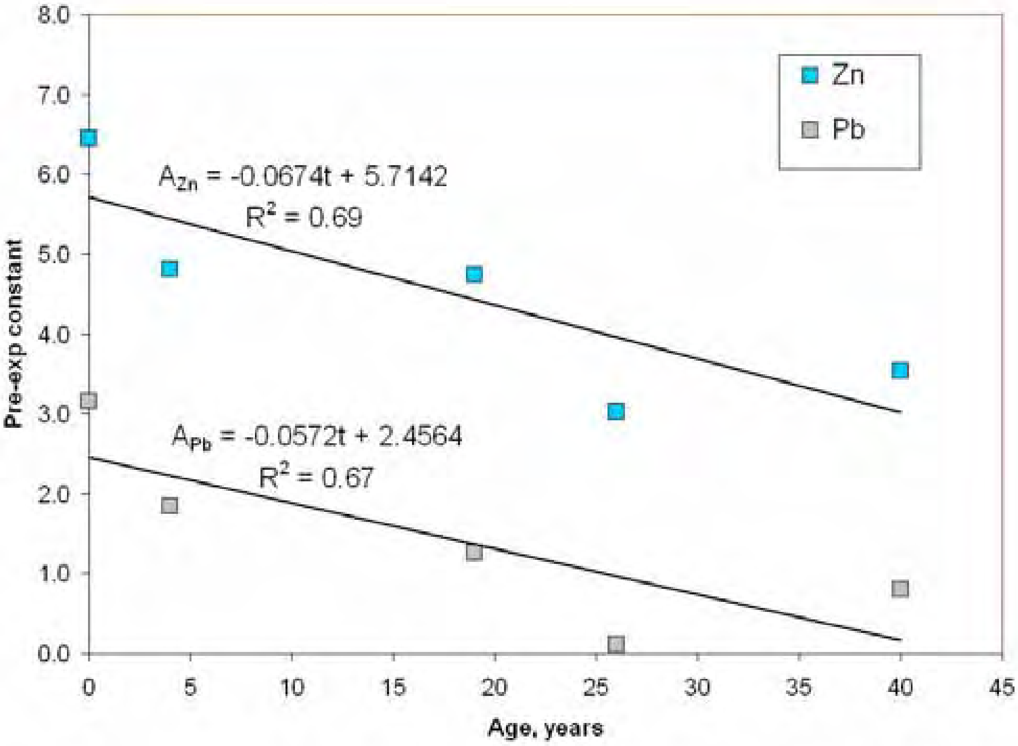


Figure C.86 The rate of Zn release, as measured by the pre-exponential factor, as a function of the age of the meter.

In conclusion, the corrosion of the brass proceeds first by dezincification of the Cu-Zn alloy, which provides porosity that allows for the release of Pb from the separate “islands” of Pb metal in the brass. The rate of dezincification is, counter-intuitively, inversely related to the amount of Zn. That is, high-Zn brasses are more resistant to leaching of Zn and hence of Pb. The rate is also a function of the age of the meter, through the pre-exponential factor. The older meters release less Pb, probably because a passivating scale layer forms. The extent of this scale coverage increases with age, although the thickness does not appear to increase.

Summary

Six residential water meters were used in side-by-side testing at the SPU Water Quality Laboratory to identify their potential Pb and Cu contributions to drinking water in first-draw stagnation samples. The meters ranged in service age from new, never used units to one that had been in service for 40 continuous years. Five of the meters were brass with up to 8% Pb content, and one was the new “no-lead” brass in which the Pb content is less than 0.2%, and Bi and Se (a regulated element) are used in its place.

This study determined that older water meters in the SPU Cedar system can contribute Pb to the drinking water at detectable levels, but significantly less than the AL. In comparison to historically-comparable items, such as Pb service lines and Pb solder, these older meters were found to be minor contributors to the overall Pb exposure at SPU due to the well-passivated surface that limited metal corrosion. Experiments with a new no-lead Envirobrass meter found that the new alloy released very low, but again detectable, levels of Pb, Bi, and Se. Bi is not regulated while Se was found to be leaching at concentrations significantly less than the MCL.

Conversely, a new leaded brass meter was found to release significant amounts of Pb initially. The experiments also found that after 7 months of simulated intermittent use, the new brass meter was still releasing approximately 7 µg Pb in a composite 1,750 mL sample. In comparison, the 4-year old and 19-year old meters by the same manufacturer released 2 µg Pb or less in the same tests. A preconditioning period would be useful to passivate the meter interior and reduce the initial Pb release in new brass meters. However, these results show that this passivation period for SPU is some time between 1 and 4 years, if Cedar tap water is used.

For most of the meters, an increase in flow rate from 1 L/min to 4 L/min did not result in increased Pb levels. The exception was the new brass meter. The new meter was found to have increased the mass of Pb released immediately after the flow rate change. After 8 days of intermittent flushing at 4 L/min, the Pb release had decreased to nearly the same level as before the flow rate increase.

The Pb from the meter could be reflected in the first-draw 1-L compliance samples due to the location of the meter relative to a faucet. The 1-L sample would draw water from the faucet and the first 26 feet of ½-inch copper plumbing, or 11.5 feet of ¾-inch copper plumbing, upstream of the faucet. Having the stagnation water from the meter be part of the SPU compliance samples is unlikely since SPU installs the water meters outside of the property line. There could be an impact if the water had stagnated in the meter and that water made its way to within the 1-L sampling volume of the faucet. For other utilities, especially those that have the water meters installed inside the houses, the meter Pb would be part of the compliance sample for those single-family residential homes where the meter is in very close proximity to the faucet.

The study also found that a physical disturbance to water meters, especially older meters, can have a significant negative impact on developed corrosion scales. The scales were found to be dislodged from the surface and resulted in very high Pb levels in the water. A period of 63 days of intermittent flushing at 1 L/min for 3 hours/day was required before the Pb levels stabilized below the AL. This information could be important to consider when planning such construction activities as main and service line replacements, utility relocations, or nearby street improvements, where moving and shaking of old meters could occur.

Scale analyses revealed that scale coverage increases with age, however thickness of the scale did not appear to increase. Brass corrosion appears to proceed first by dezincification of the Cu-Zn alloy, that allows for the release of Pb from the separate "islands" of Pb metal in the brass. The rate of dezincification may be inversely related to the amount of Zn and may also be a function of the age of the meter. Older meters appear to release less Pb, probably because a passivating scale layer forms.

WASHINGTON AQUEDUCT LEAD SERVICE LINE PILOT STUDY

A pilot study using excavated lead service piping from the DCWASA distribution system was conducted by the Washington Aqueduct (WA) to evaluate a variety of corrosion control treatment options. Water was circulated through the sections of lead service piping that had been installed in the pilot apparatus, and water quality samples were collected and analyzed for total and dissolved lead, plus a variety of other parameters. This evaluation was a separate study, not funded or managed through this project, however data was shared with the project team to expand our understanding of lead leaching from lead service piping (CH2M Hill 2004). Issues related to the comparability of lead pipe specimens originally installed in the racks, operational control of influent pH, alkalinity, and orthophosphate levels to the racks, as well as the potential for temperature effects, complicated the interpretation of water quality effects on lead release from the lead pipes used in WA study. Therefore, results obtained by the Aqueduct were used to indicate general trends in the amount of lead derived from lead piping and the impact that orthophosphate treatment may have on lead levels, rather than relative contributions of lead pipe to lead levels at the tap. Scale analyses were completed on lead pipe specimens removed from the pilot apparatus. These analyses were completed by the University of Cincinnati as part of this research project.

Objectives

The Aqueduct's goals for the pilot study were to evaluate the impacts that phosphate inhibitor dosage rates, using high chlorine or low chlorine doses, and switching from free chlorine to chloramine might have on lead release. The experiments examined different corrosion inhibitor types (e.g., phosphoric acid and zinc orthophosphate) and inhibitor doses, and disinfection strategies. For purposes of this project, these data were used to:

- assess relative lead contributions from lead service piping exposed to the water chemistry evaluated in the study,
- evaluate the relative effectiveness of the phosphate inhibitors for reducing lead levels from lead piping.

Methods and Materials

This section describes the methods and materials used by the Washington Aqueduct for the lead service line pilot study. The Aqueduct pilot study consisted of 7 racks constructed in parallel, with 3 loops and 12 coupons in each rack. Lead service line piping excavated from the Washington D.C. water distribution system was used to construct the pipe loops for each rack. Each loop contained two or three sections of lead service piping with a total length of 13 feet of ¾ -inch lead service piping, providing for a sample volume of 1.1 liters per loop (Figure C.87) and a leg constructed of coupons connected by hose to be removed for scale analysis. Water from the Aqueduct's Dalecarlia WTP was used as source water for the testing, with additional treatment chemicals added to the influent filtered water flow stream to simulate finished water quality under different conditions.

The pilot testing was conducted from January, 2005 through October, 2006. The loops were conditioned with WA finished water beginning on January 7, 2005 and were put on automatic mode and fed chemically conditioned water on March 7, 2005 (TWEG 2005, TWEG

2006, Cadmus Group, 2007). Each rack was operated under a different water quality condition as shown in Table C.21.

Figure C.87 Photograph of Washington Aqueduct Pipe Rack

Water was pumped in a single pass through the racks for 16-hours, followed by an 8-hour stagnation period. The racks were operated seven days a week. Water quality samples were collected on Monday through Friday and analyzed for the following:

- Total and dissolved lead
- pH and alkalinity (as CaCO3)
- Calcium
- Total dissolved solids
- Turbidity
- Dissolved inorganic carbon (DIC)
- Heterotrophic Plate Count (HPC),
- NH3 (as N)
- Nitrite and Nitrate (as N)

Sections of lead service piping were removed from the pilot system periodically and sent to the University of Cincinnati (UC) for analysis of the scale formation on the internal surfaces of the pipes.

Table C.21
Washington Aqueduct Pipe Rack Description

Rack	Description	pH	Chlorine (mg/L)	Chloramines (mg/L)	Phosphate (mg/L)
1	High chloramines, zinc orthophosphate, decrease zinc orthophosphate dose over time	7.7	0	3.5	3.0
2	High chloramines with phosphoric. acid, decrease phosphoric acid dose over time	7.7	0	3.5	3.0
3	switch between free chlorine and chloramines - constant phosphoric acid dose	7.7	switch	3.5	3.0
4	High chloramines - no corrosion inhibitor	7.7	0	3.5	0.0
5	Low chloramines with constant phosphoric acid dose	7.7	0	2	3.0
6	High chloramines with constant phosphoric acid dose	7.7	0	3.5	3.0
7	Control - WA finished water	7.7	0	3.5	3.0

Water Quality Changes

On September 5th, 2005 Rack 3 was switched from chloramine to free chlorine, then switched back to chloramine on November 4th.. This switch was intended to simulate a fall conversion to free chlorine. On September 12th, 2005 the phosphate concentration in Rack 2 was lowered from a target of 3 mg/L to a target of 2 mg/L. On November 14th, 2005 the phosphate concentration was lowered again from a target of 2 mg/L to 1 mg/L.

Operation of Racks 1 (Zinc Orthophosphate), 4 (no orthophosphate inhibitor) and 5 (low chloramines dose) were discontinued February 3, 2006. The remaining racks (Racks 2, 3, 6 & 7) continued to be operated, and data collected through October, 2006 was received. The phosphate dose in Racks 2 and 6 was lowered from 3 mg/L as PO_2 to 1 mg/L as PO_4 in February, 2006. Rack 3 continued to have a 3 mg/L phosphate dosage. Ammonia to all three test racks in service (excluding rack 7, the control rack) was turned off from 4/14/06 to 5/12/2006 to simulate a spring conversion to free chlorine. This was done as previously discussed to observe the effect of a conversion to free chlorine with typical spring water temperature.

Results and Discussion

Figures C.88 through C.94 contain graphical summaries of total and dissolved lead measured from each rack. Results indicate that total and dissolved lead levels from all loops appear to have stabilized after approximately 6 to 9 months of operation. The majority of lead measured before stabilization was in the form of particulate lead, with the exception of Rack 4 (high chloramine, no inhibitor). This rack also took the longest to exhibit stable total lead levels. Several racks appeared to exhibit a temperature dependence on lead levels.

Total lead levels continued to decrease in Rack 2 after orthophosphate dosages were reduced first to 2 mg/L, then to 1 mg/L as PO4. Lead levels measured during the 2005 and 2006 conversion to free chlorine in Rack 3 appeared to show a drop in lead concentrations when the switch from chloramine to free chlorine was made. The data did not show a significant increase in lead release after switching back to chloramines in 2005, but showed an increase after the switch back to chloramines in 2006 which may have been due to temperature effects.

Issues related to the comparability of lead pipe specimens originally installed in the racks, operational control of influent pH, alkalinity, and orthophosphate levels to the racks, as well as the potential for temperature effects, complicate the interpretation of water quality effects on lead leaching from the lead pipes used in this evaluation. Therefore, results from the WA pipe rack study were used to indicate general trends in the amount of lead derived from lead piping, rather than relative contributions of lead pipe to lead levels at the tap. Slight increases in lead release may have been caused by switching from free chlorine to chloramines or may be attributed to temperature effects. High particulate lead was measured in racks using orthophosphate, and it took from 7 to 9 months for lead levels to stabilize in the racks. The rack with no inhibitor (Rack 4), had a higher percentage of dissolved lead than in racks with an inhibitor.

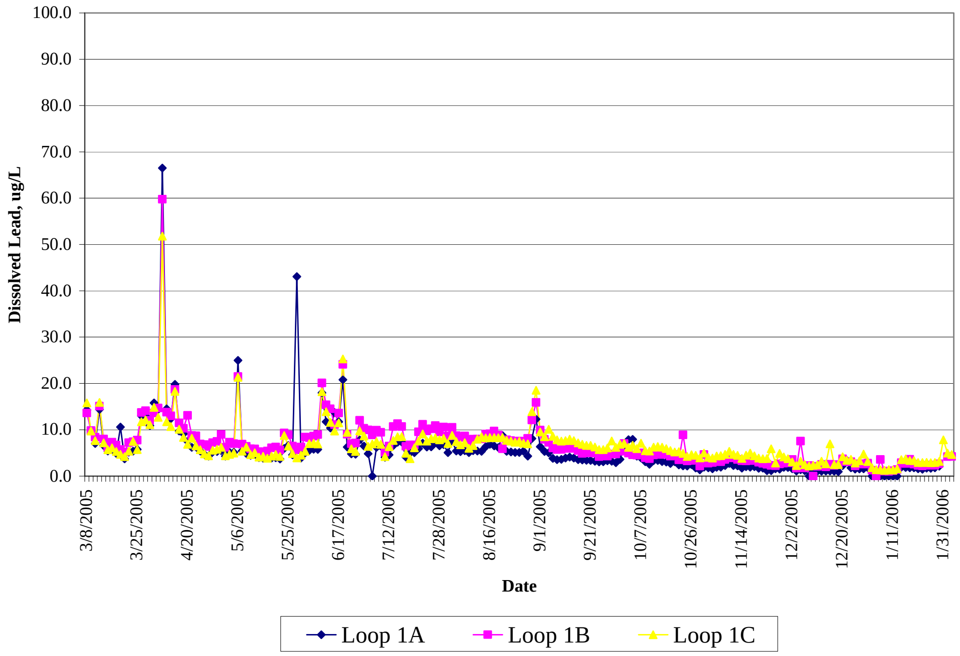
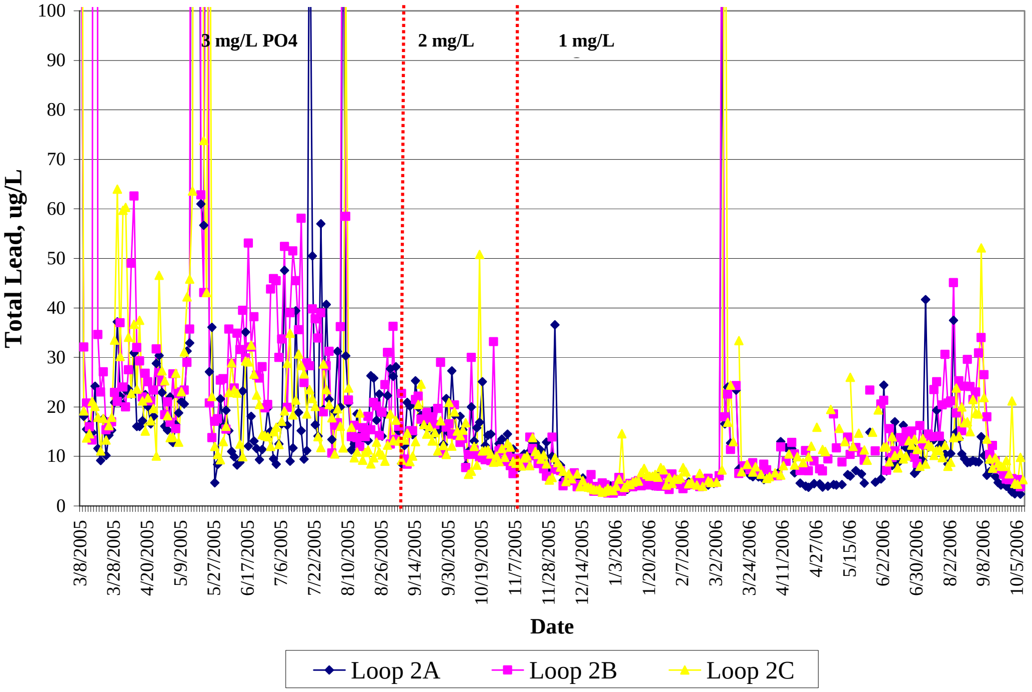


Figure C.88 Rack 1 – High chloramines with zinc orthophosphate. Decrease in zinc orthophosphate with time

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.



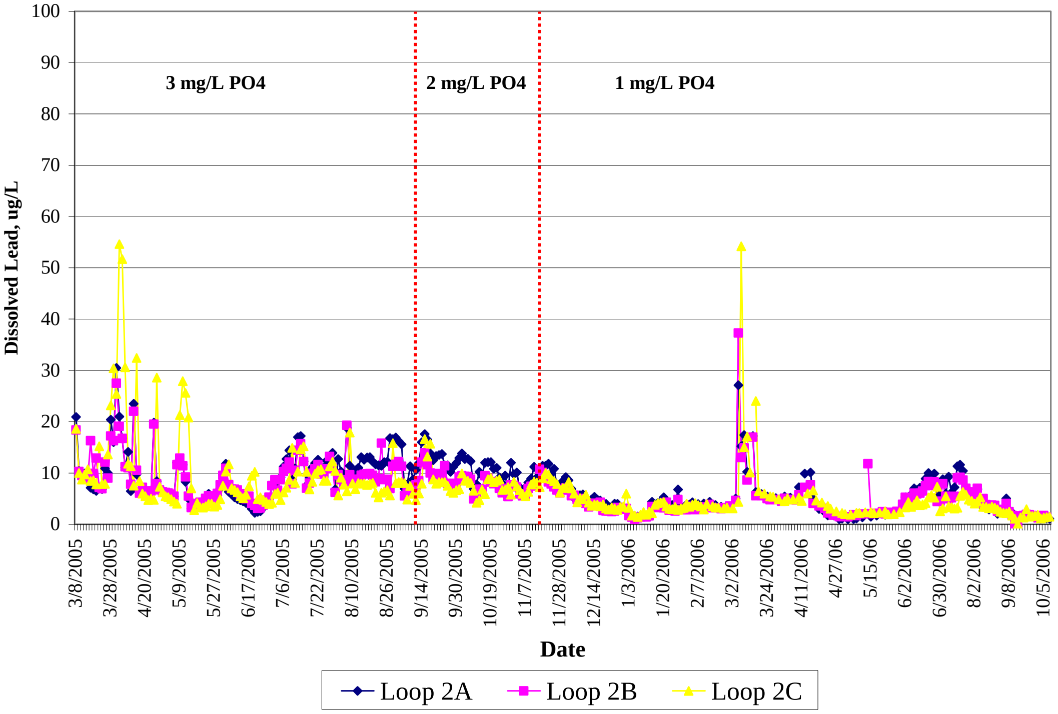


Figure C.89 Rack 2 – High chloramines and phosphoric acid. Decrease in phosphoric acid dose with time

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

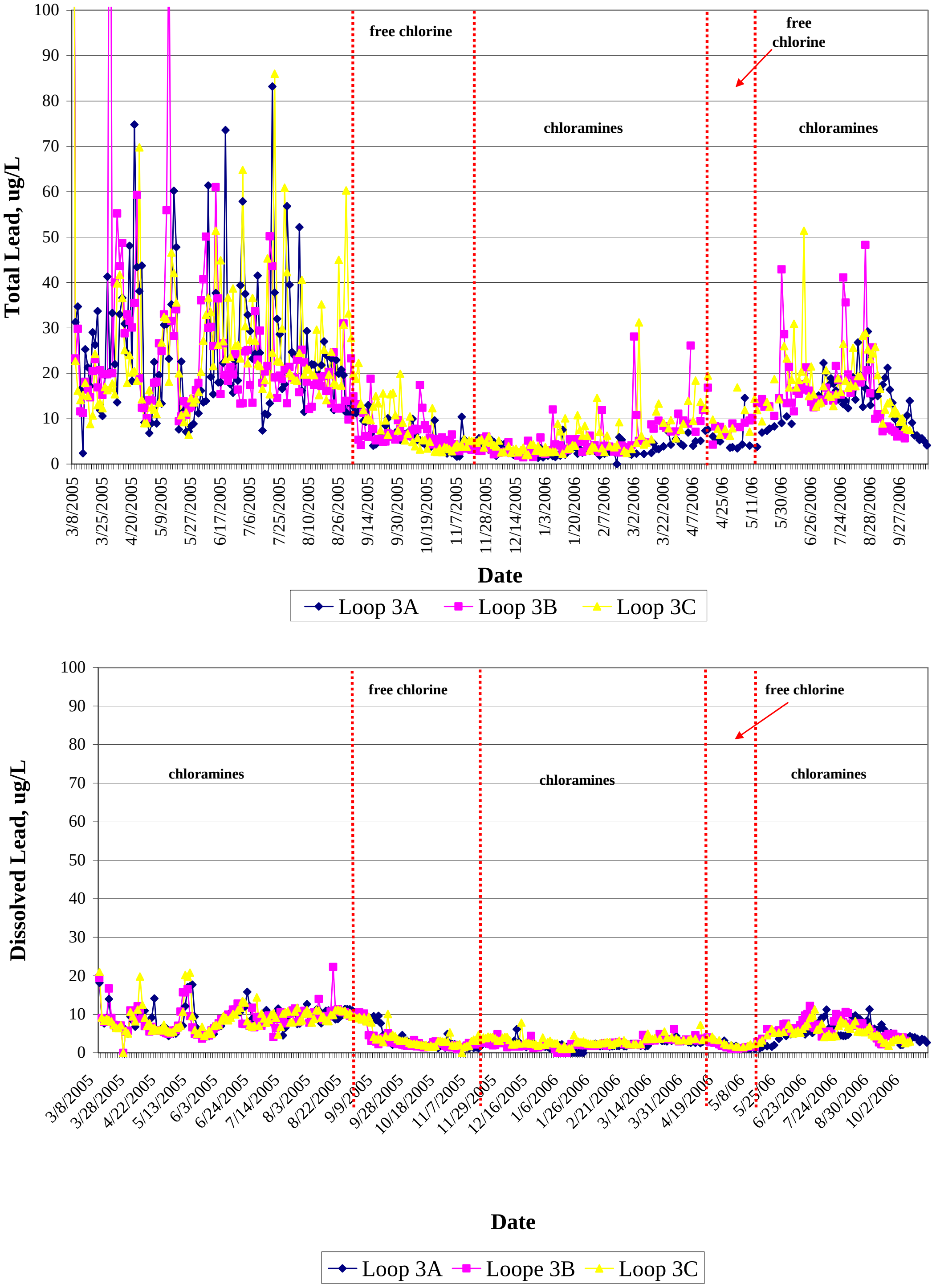


Figure C.90 Rack 3 - Switch between free chlorine and chloramines at constant phosphoric acid dose

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

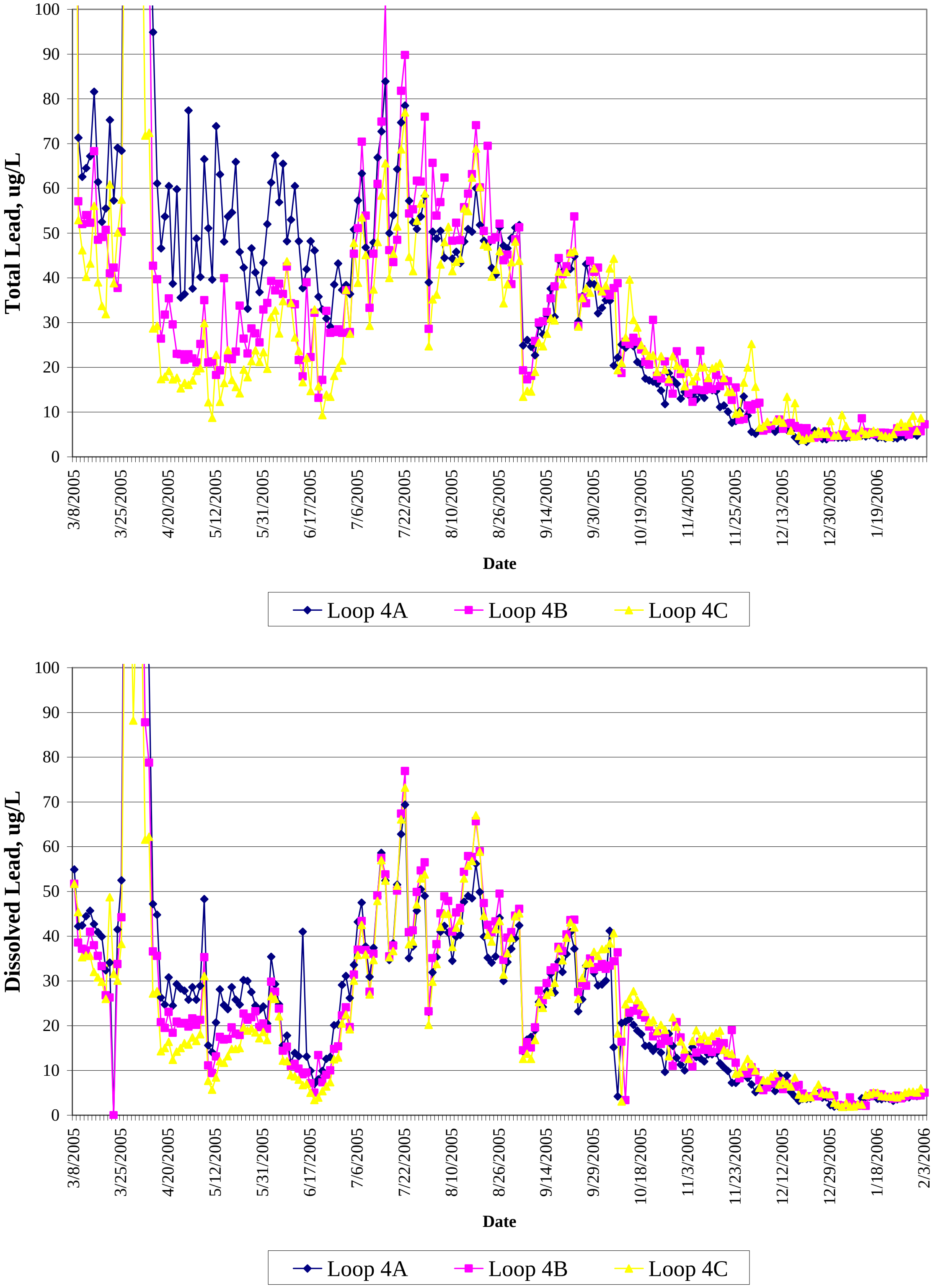
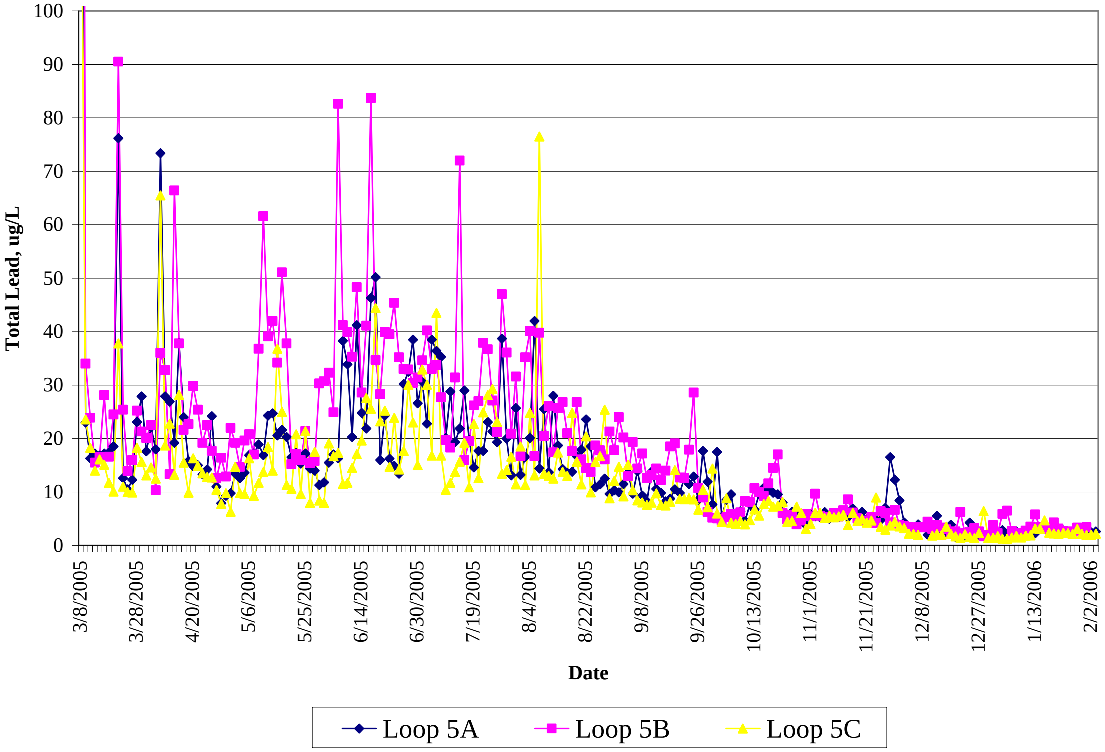


Figure C.91 Rack 4. High chloramines, no corrosion inhibitor

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.



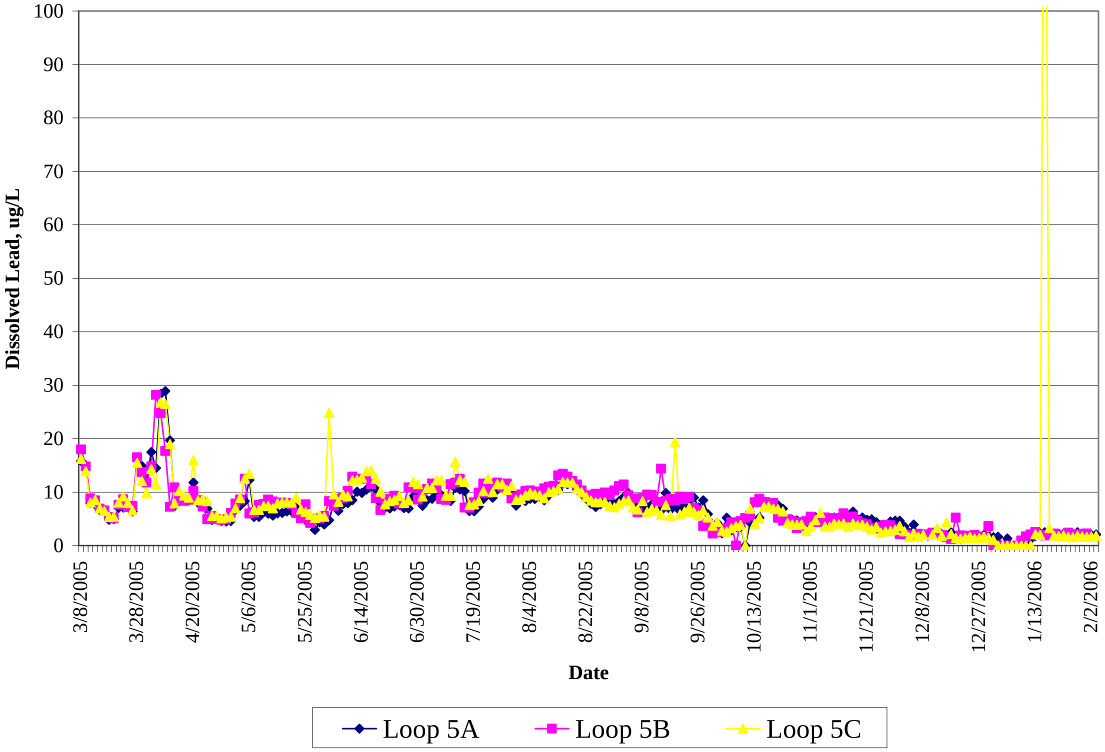
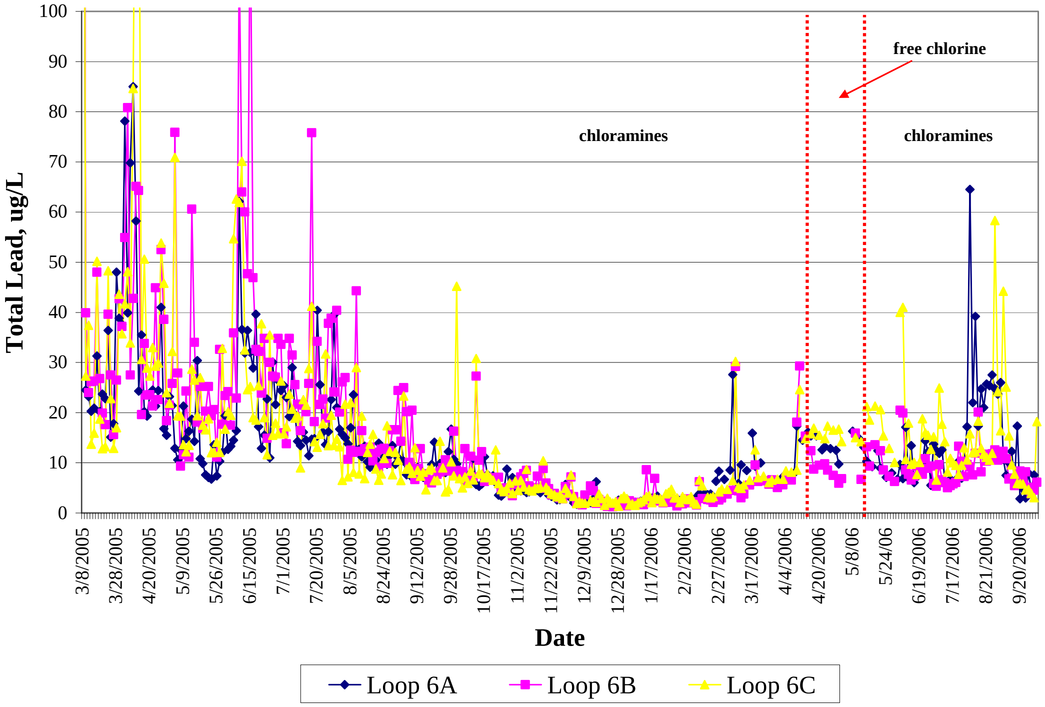


Figure C.92 Rack 5 - Low chloramines with constant phosphoric acid dose

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.



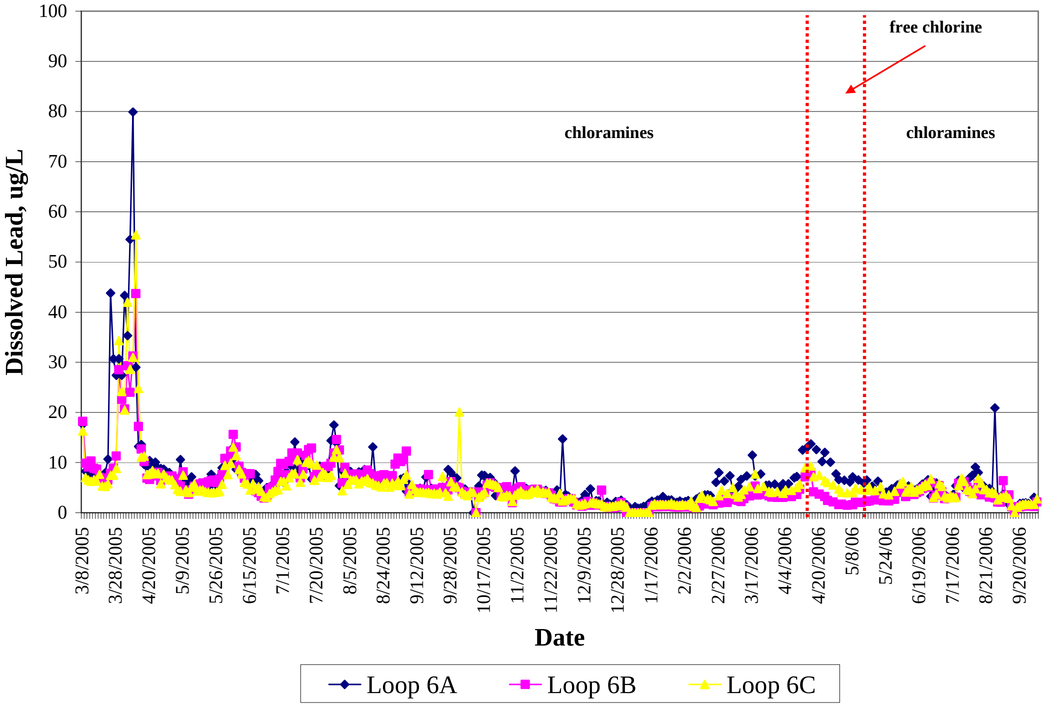
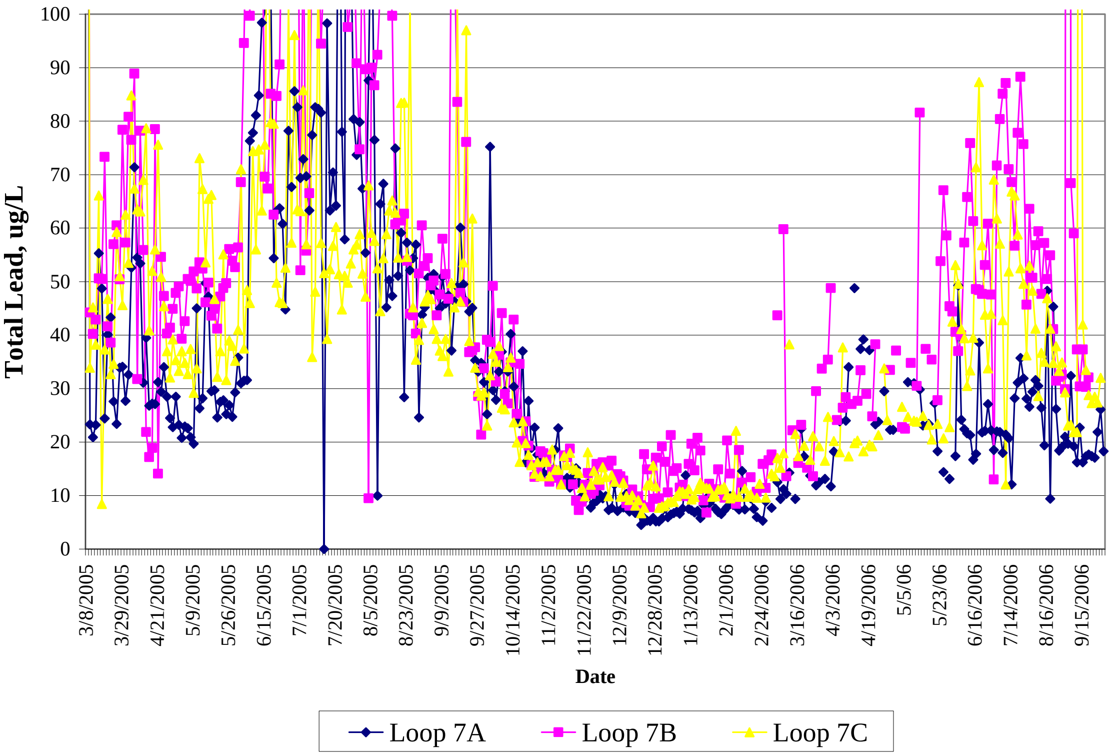


Figure C.93 Rack 6 – High chloramines at a constant phosphoric acid dose

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.



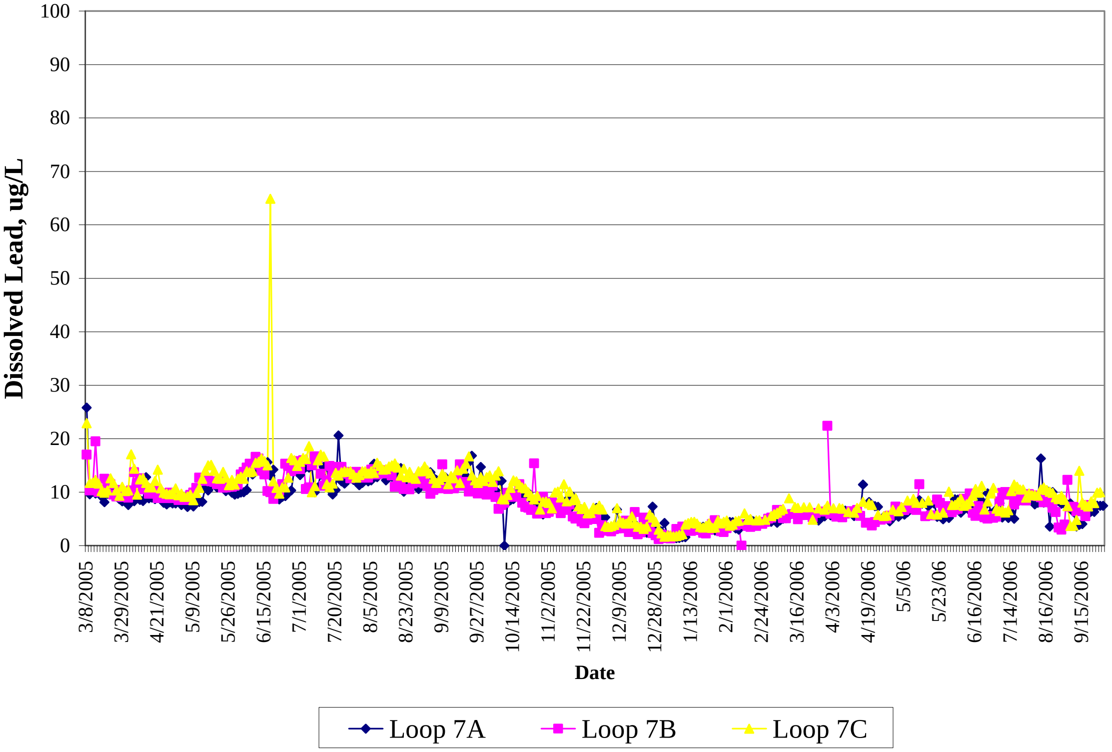


Figure C.94 Rack 7 – Control – WA Finished Water

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scale Analyses

Samples of lead service piping from the Washington Aqueduct pilot study were harvested and sent to the University of Cincinnati for analysis of the interior scales as part of this research project. Table C.22 lists the samples received and the laboratory numbers assigned to each of these pipe loop samples.

Table C.22
Washington Aqueduct Pipe Samples Received by Universtiy of Cincinnati for Scale Analysis

Pipe rack	Date removed	Laboratory number	Description	Disinfectant	Phosphate treatment
1	12-Oct-2005	10_PP01	Lead pipe	Chloramine	Zn o-phosphate
2	12-Oct-2005	10_PP02	Lead pipe	Chloramine	Phosphoric acid
3	12-Oct-2005	10_PP03	Lead pipe	Chlorine/chloramine	Phosphoric acid
4	12-Oct-2005	10_PP04	Lead pipe	Chloramine	None
5	12-Oct-2005	10_PP05	Lead pipe	Low chloramine	Phosphoric acid
6	12-Oct-2005	10_PP06	Lead pipe	Chloramine	Phosphoric acid
7	12-Oct-2005	10_PP07	Lead pipe	Chloramine	Phosphoric acid
1	04-Nov-2005	10_PP08	Lead pipe	Chloramine	Zn o-phosphate
2	04-Nov-2005	10_PP09	Lead pipe	Chloramine	Phosphoric acid
3	04-Nov-2005	10_PP10	Lead pipe	Chlorine/chloramine	Phosphoric acid
4	04-Nov-2005	10_PP11	Lead pipe	Chloramine	None
5	04-Nov-2005	10_PP12	Lead pipe	Low chloramine	Phosphoric acid
6	04-Nov-2005	10_PP13	Lead pipe	Chloramine	Phosphoric acid
7	04-Nov-2005	10_PP14	Lead pipe	Chloramine	Phosphoric acid
2	09-Jun-2006	10_PP15	Lead pipe	Chloramine	Phosphoric acid
3	09-Jun-2006	10_PP16	Lead pipe	Chlorine/chloramine	Phosphoric acid
6	09-Jun-2006	10_PP17	Lead pipe	Chloramine	Phosphoric acid
7	09-Jun-2006	10_PP18	Lead pipe	Cfhloramine	Phosphoric acid

The number of samples collected was insufficient to draw statistically significant conclusions. However, some general observations can be made based on the results of the analyses:

- From the first sample set taken on September 13, 2005 to the second sample set taken on November 2, 2005, the mineral compound litharge (PbO) decreased while pyromorphite (hydroxypypromorphite ($Pb_5(PO_4)_3(OH)$)) increased. Since litharge is much more soluble that pyromorphite, this is an indication that the pipe scale was becoming more stable.
- Rack 3 was dosed chlorine as a disinfectant during the time that both samples were taken. The other racks were dosed chloramines. In Rack 3, platternite, PbO_2 or [Pb(IV)], increased and litharge, PbO or [Pb(II)], decreased in Layer 1 from the first sample to the second sample set.
- The chemical element analysis of both rounds of samples indicates that the scale in the pipe loops is heterogeneous. Heterogeneous scales tend to be more stable than homogeneous scales.

Water chemistry over time was also provided for each loop in each rack. In Table C.23, the averages of all analyses are presented. Particulate Pb greatly predominated over dissolved Pb for all except Rack 4 (high chloramines – no corrosion inhibitor). Both particulate and dissolved Pb decreased with time, but the effect was much stronger for particulate Pb. The calcium carbonate-related parameters (pH, Ca, DIC, alkalinity) were essentially the same for all racks, but varied with time, reflecting seasonal changes. Rounds 1 and 2 (October and November 2005) averaged about 20^{o}C, whereas Round 3 (June 2006) was closer to 10^{o}C. The third round of analyses showed the highest nitrate and nitrite values, by a considerable margin, perhaps reflecting diminished activity of denitrifying bacteria in the winter months.

Table C.23, part 1. Water chemistry parameters (averages of 3 loops)

Rack #	Round	pH	Temp	PO_4 (ppm)	Fluoride (ppm)	Calcium (ppm)	DIC (ppm)	Alkalinity (ppm as $CaCO_3$)	Total Pb (ppb)	Dissolved Pb (ppb)
1	1	7.9	21.5	3.69	0.88	32.5	20.0	83	110	8.69
1	2	7.8	20.3	3.17	0.27	38.1	25.9	102	29.7	4.54
1	(3)	7.7	10.6	3.06	0.95	n.d	n.d	76	4.7	2.57
2	1	7.8	21.8	3.55	0.84	33.2	20.2	80	29.4	9.8
2	2	7.8	20.5	2.33	0.30	38.9	26.0	102	15.4	11.3
2	3	7.8	13.1	1.31	0.94	n.d.	n.d.	76	7.9	5.6
3	1	7.7	21.6	3.36	0.84	32.6	20.2	79	26.3	8.8
3	2	7.8	20.6	3.53	0.27	38.4	25.4	102	6.7	2.4
3	3	7.7	13.4	3.12	0.95	n.d.	n.d.	74	5.1	2.5
4	1	7.8	21.8	0.43	0.89	33.6	20.6	78	50.6	36.4
4	2	7.9	21.6	0.48	0.28	39.2	25.9	102	29.0	25.2
4	(3)	7.8	10.5	0.49	0.94	n.d.	n.d.	82	8.3	7.0
5	1	7.9	21.7	2.88	0.85	33.1	20.4	80	23.9	9.4
5	2	7.9	20.8	3.30	0.28	38.6	25.5	102	8.6	5.9
5	(3)	7.8	15.0	2.98	0.94	n.d.	n.d.	81	3.6	3.9
6	1	7.8	21.7	3.10	0.85	33.1	20.7	79	25.7	9.3
6	2	7.8	20.6	3.45	0.28	39.4	26.0	103	8.2	4.8
6	3	7.7	13.3	2.29	0.93	n.d.	n.d.	75	5.4	3.4
7	1	7.8	21.9	2.88	0.90	41.8	21.1	83	68.5	11.8
7	2	7.7	20.9	3.17	0.92	48.3	26.0	105	37.4	10.1
7	3	7.8	13.2	2.66	0.83	n.d.	n.d.	76	15.5	4.5

n.d. = not determined; numbers in parentheses indicate sample rounds that have water quality data, but no scale data

(continued)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table C.23, part 2. Redox-sensitive parameters (averages of 3 loops)

Rack #	Round	ORP (mv)	Free chlorine (ppm)	Total Chlorine (ppm)	Total NH_3 (ppm)	Nitrite (ppm)	Nitrate (ppm)
1	1	352	0.31	2.70	1.06	0.007	1.57
1	2	439	0.18	2.60	1.38	0.009	1.39
1	(3)	n.d.	0.12	**3.17**	n.d.	0.012	**2.28**
2	1	359	0.29	2.55	1.07	0.008	1.56
2	2	441	0.13	2.53	1.13	0.009	1.40
2	3	n.d.	0.75	2.83	n.d.	0.024	**2.31**
3	1	340	0.50	**3.06**	1.16	0.008	1.56
3	2	**632**	**1.99**	2.66	0.04	0.008	1.37
3	3	n.d.	0.88	**3.09**	n.d.	n.d.	**2.31**
4	1	375	0.27	2.56	0.99	0.004	1.55
4	2	448	0.17	2.67	1.14	0.007	1.44
4	(3)	388	0.11	**3.14**	n.d.	0.015	**2.31**
5	1	343	0.12	1.66	0.64	0.012	1.58
5	2	473	**1.67**	1.89	0.79	0.008	1.41
5	(3)	n.d.	0.54	1.89	n.d.	0.027	**2.34**
6	1	374	0.35	2.56	0.99	0.004	1.57
6	2	458	0.20	2.61	1.15	0.010	1.42
6	3	381	0.77	2.95	n.d.	0.010	**2.35**
7	1	335	0.14	**3.13**	0.92	0.009	1.56
7	2	466	0.15	2.97	0.93	0.009	1.37
7	3	n.d.	0.15	**3.35**	n.d.	0.010	**2.32**

n.d. = not determined; bold values are higher than normal range; numbers in parentheses indicate sample rounds that have water quality data, but no scale data

Initially Heterogeneous Scale Conditions

Visual examination of the received pipes and their chemical and mineralogical characteristics revealed that the set of pipes installed in the racks spanned a considerable range of properties. This is revealed, for example, by parameters such as Si content, which varies from 1 to 10% of the scale solids, but is not a parameter affected by any of the water treatments applied. Because this initial heterogeneity introduces an unknown variability that could mask any time trends in the experiments, it was decided to group the pipes into categories and only make comparisons within a given category.

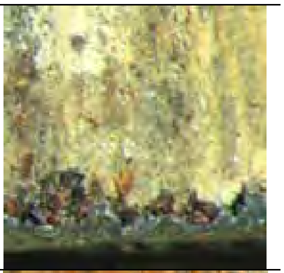
Pipe samples were divided into three groups based on macroscopic appearance of the scale surface, as shown in Table C.24. Each pipe received was assigned to a category by two different investigators. Agreement in assignments was 17 out of 18 samples. Arranging the pipe samples by rack number (Table C.25) shows that each rack, with the exception of 7 (control rack), contained a heterogeneous assortment of original scale types. This initial condition makes it difficult to characterize changes with time in the individual racks, and this was not attempted.

Mineralogy of scales by x-ray diffraction

Each pipe was cut in half lengthwise and one half scrapped to remove the scale. Sufficient volume was present to remove two successive layers, designated L1 (closest to the water) and L2, closest to the pipe. A typical x-ray pattern is shown in Figure C.95. The same array of minerals is seen in both layers, but the relative peak heights change.

By assigning the largest peak a value of 100, the other peaks can be measured relative to the strongest peak and a quantitative estimate of mineral abundance obtained. In Table C.26, average mineralogies for each scale type are given.

Table C.24
Categories of initial scale properties

	Colors	X-ray mineralogy	Macrophoto	Microphoto
Type A	Dark brown, even	Pyromorphite < plattnerite		
Type B	Lighter brown, spots and lines of white	Pyromorphite >> plattnerite		
Type C	Lighter brown, even	Pyromorphite > plattnerite		

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table C.25
Categories of scales in pipe specimens from each pipe rack (by round)

Pipe rack	Round	Laboratory number	Scale category
1	1	10_PP01	B
1	2	10_PP08	A
2	1	10_PP02	B
2	2	10_PP09	A
2	3	10_PP15	B
3	1	10_PP03	B
3	2	10_PP10	B
3	3	10_PP16	A
4	1	10_PP04	C
4	2	10_PP11	B
5	1	10_PP05	A
5	2	10_PP12	C
6	1	10_PP06	B
6	2	10_PP13	B
6	3	10_PP17	C
7	1	10_PP07	B
7	2	10_PP14	B
7	3	10_PP18	B

Note the much greater abundance of litharge close to the pipe surface, whereas pyromorphite and plattnerite were most abundant in the top layer. The Pb carbonates were distributed relatively evenly in the two layers, with hydrocerussite dominant over cerussite in all cases. No time trends wer apparent in the data except for an increase in plattnerite and pyromorphite at the expense of litharge in Type B scales (Figure C.96). This same trend is present in Type A scales, but the sample size is too small to calculate averages.

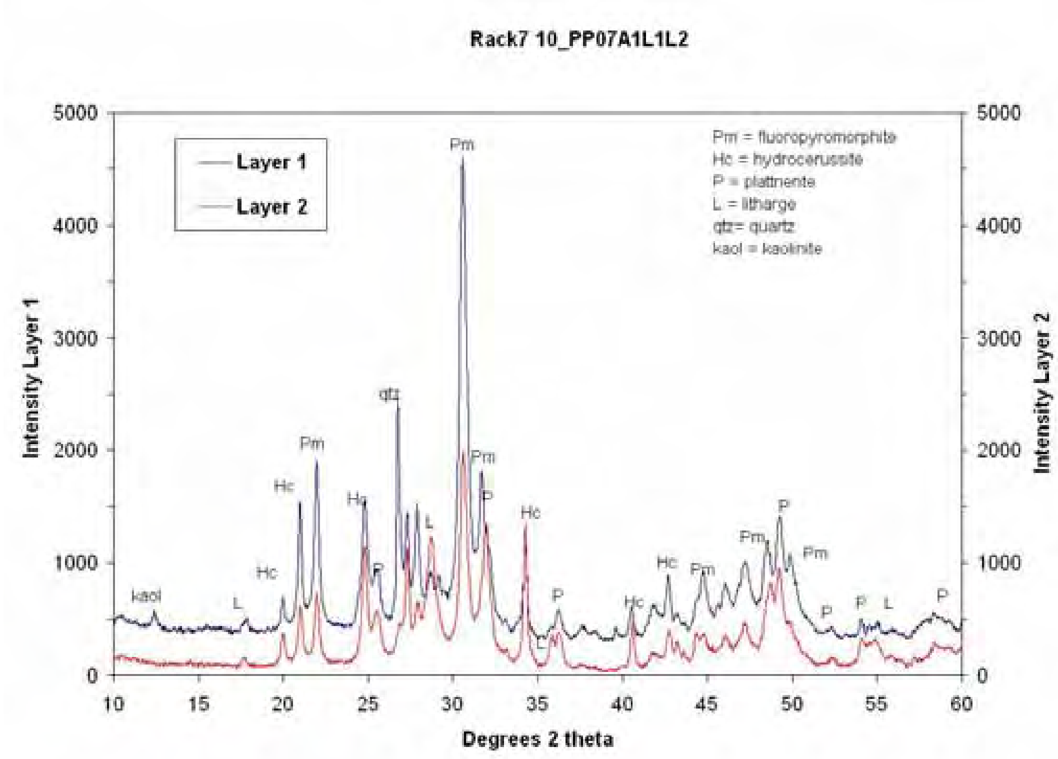


Figure C.95 XRD patterns for rack 7 scales show pyromorphite dominant over plattnerite in the outer layer, accompanied by abundant hydrocerussite. The inner layer is still dominated by pyromorphite but with abundant litharge.

Table C.26
Washington Aqueduct pipe loops - summary of x-ray diffraction results

	Scale type	Pyromorphite $Pb_5F(PO_4)3$	Plattnerite PbO_2	Cerussite $PbCO_3$	Hydrocerussite $Pb_3(CO3)_2(OH)_2$	Litharge PbO
Layer 1						
	A	66	100	5	22	21
	B	100	41	18	30	22
	C	100	69	14	46	16
Layer 2						
	A	73	49	13	34	88
	B	70	45	21	45	82
	C	78	29	5	41	66

Relative intensities of the principal peaks for the dominant minerals, quartz peaks excluded
(Strongest peak is arbitrarily assigned a value of 100)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

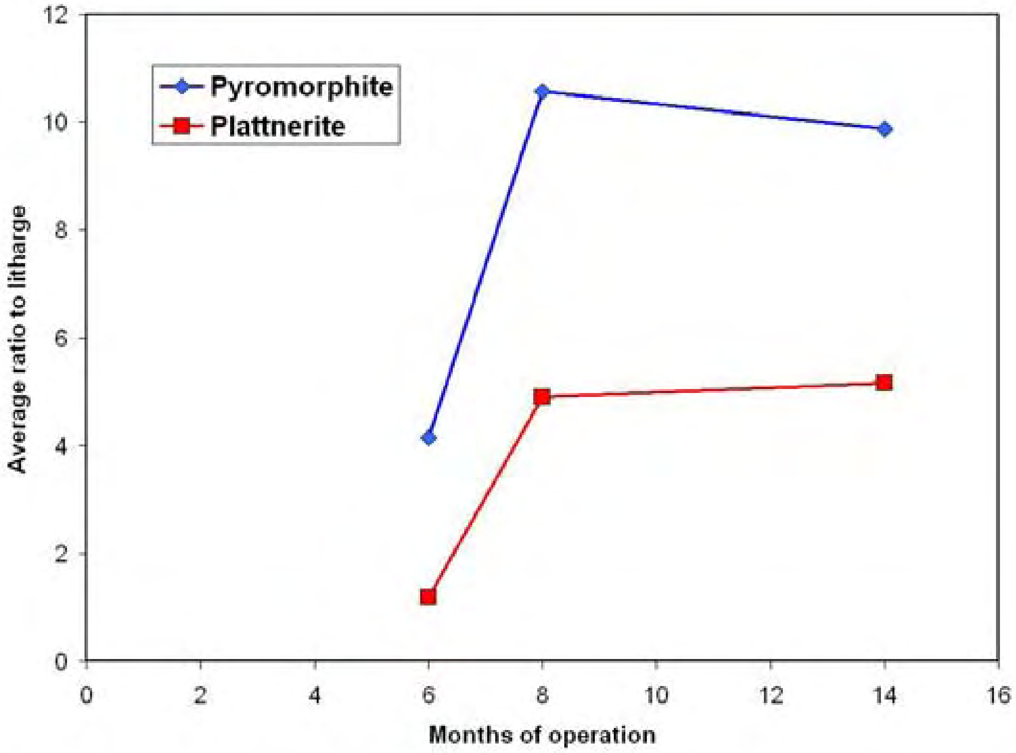


Figure C.96 X-ray mineralogy of Layer 1, Type B scales as a function of reaction time shows pyromorphite dominant over plattnerite in the outer layer and that both increase at the expense of litharge from round 1 to round 2.

Chemistry of scales by x-ray fluorescence

Scale chemistry showed little variation among the three types, but Layer 1 and Layer 2 differed profoundly (Table C.27). Pb was appreciably higher in Layer 2, whereas most other elements were higher in Layer 1. This pattern suggests a scale structure in which Pb minerals dominate close to the pipe, but this layer is overlain by a remarkably heterogeneous layer rich in Fe and Mn oxides. Also, phosphate is much higher in Layer 1, consistent with the distribution of pyromorphite seen by X-ray diffraction. No Fe or Mn-bearing minerals were detected by XRD, suggesting that these elements were present in amorphous phases. It is also noteworthy that Layer 1 had quite high vanadium (V) levels, unlike other utilities surveyed.

The most abundant element in Table C.27 after Pb is Ca. In most scales from other cities, high Ca indicates the presence of the mineral calcite ($CaCO_3$). This mineral is absent, however, in all x-ray diffraction patterns from these samples. Instead, the Ca is present in the phosphate phases. Figure C.97 shows the relationship between Ca and P for all samples.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table C.27
Scale chemistry arranged by scale type and layer (values in %)

Sample		Mg	Ba	Pb	Zn	Cu	Fe	Mn	V	Ca	Cl	S	P	Si	Al
Layer 1															
Type A	L1	0.16	0.07	42.8	0.42	0.62	0.64	0.62	0.19	10.1	0.56	0.65	2.81	2.36	0.90
Type B	L1	0.16	0.06	39.0	0.12	0.34	0.67	0.71	0.11	8.90	0.58	0.80	2.19	2.64	1.06
Type C	L1	0.27	0.04	42.4	0.12	0.49	0.75	1.05	0.17	9.38	0.56	0.47	2.33	2.48	1.28
Overall average	L1	0.18	0.06	40.4	0.19	0.43	0.68	0.75	0.14	9.23	0.57	0.71	2.35	2.55	1.06
Layer 2															
Type A	L2	0.10	0.03	46.3	0.10	0.15	0.17	0.21	0.04	8.70	0.48	0.66	1.15	1.48	0.86
Type B	L2	0.12	0.04	46.4	0.05	0.15	0.17	0.14	0.05	6.79	0.42	0.44	1.40	0.66	0.33
Type C	L2	0.17	0.03	45.5	0.04	0.13	0.19	0.16	0.05	5.42	0.48	0.50	1.42	0.73	0.54
Overall average	L2	0.13	0.03	46.2	0.06	0.15	0.17	0.16	0.05	6.99	0.44	0.50	1.34	0.85	0.49

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

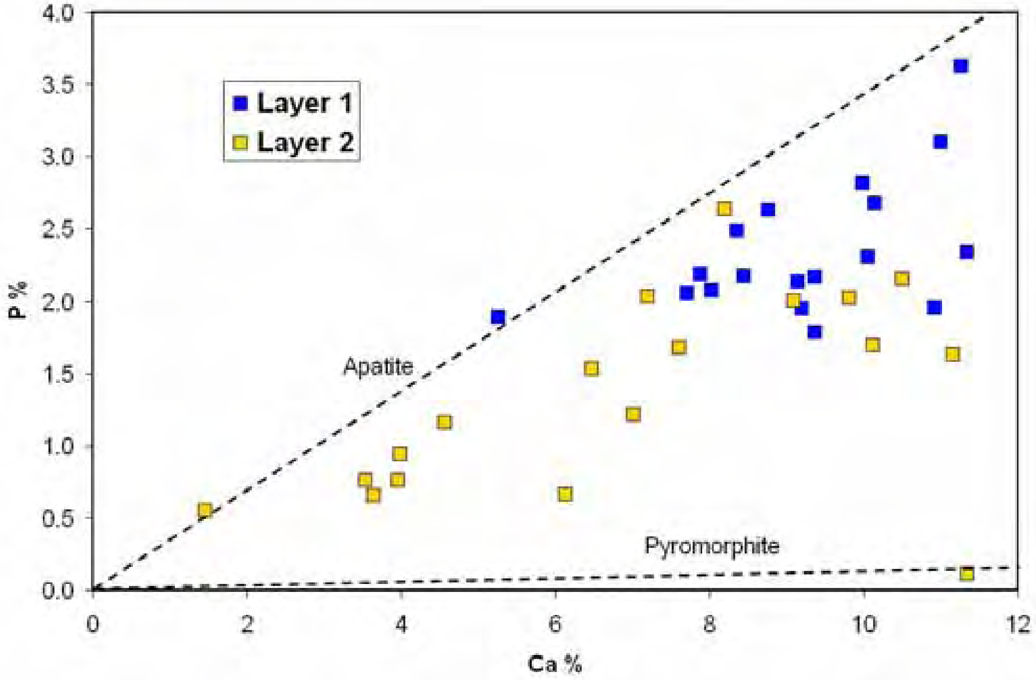


Figure C.97 Calcium and phosphate contents of scale layers 1 and 2. End-member apatite and pyromorphite are shown for comparison.

There is an isostructural series of phosphate minerals comprising apatite, pyromorphite, and vanadinite:

apatite $Ca_5(PO_4)_3X$
pyromorphite $Pb_5(PO_4)_3X$ where X = F, Cl, or OH
vanadinite $Pb_5(VO_4)_3X$

Figure C.97 indicates that the phosphates in these scales are intermediate between pyromorphite and apatite. Substitution of V for P averages 5.4 % in Layer 1 and 3.8 % in Layer 2, so there was an appreciable vanadinite component as well.

Relationship of scale chemistry to water quality

Because of the initial heterogeneity of the scales, only limited conclusions can be drawn about the relationship between scale chemistry and water chemistry. All pipe loops showed particulate Pb levels initially. After about 8 months, a more stable pattern emerged (Figure C.98). Accordingly, only the last round of water quality data, from November 2005 to May 2006 was used in the comparisons.

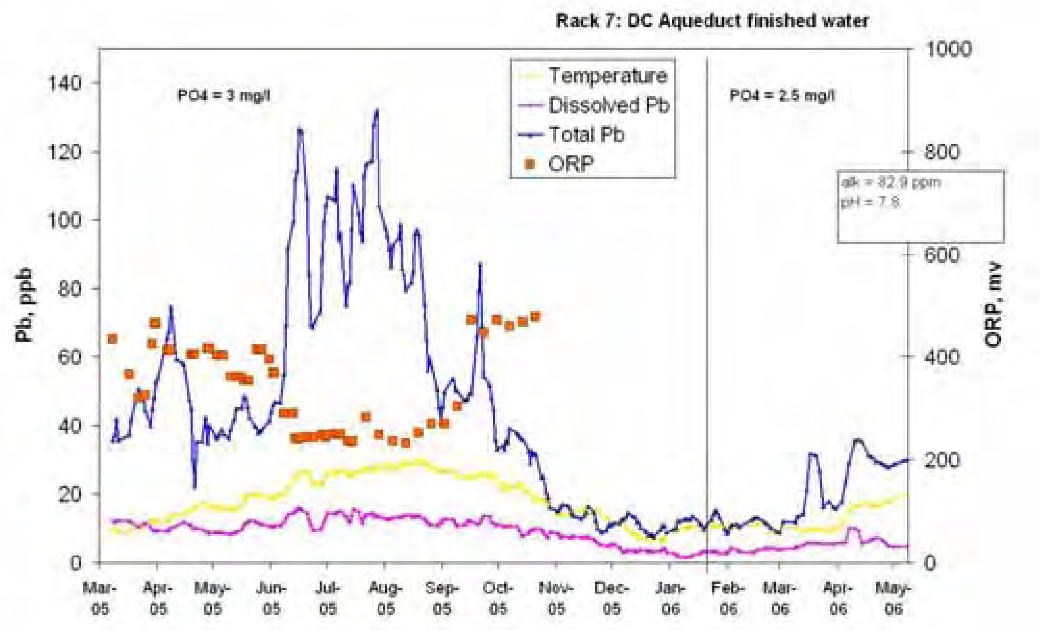


Figure C.98 Water quality parameters through time for rack 7 (finished water) shows initially high and noisy particulate Pb levels. Values stabilize after 8 months, although as temperature rises in the spring, levels again increase and remain above the action level for total Pb.

After stabilization, both particulate and dissolved Pb were present for all racks except 5. The average total Pb for the final period was 7.3 µg/l and dissolved was 4.2, leaving 3.1 µg/l of particulate Pb for all racks combined. The particulate/dissolved ratio was higher for racks that switched between chlorine and chloramine compared to racks with chloramine only (Table C.28).

Table C.28
Pb and PO_4 in water for Nov 2005 – May 2006

Rack	Total Pb µg/l	Dissolved Pb µg/l	Particulate Pb µg/l	Dissolved PO_4 mg/l	Disinfectant
1	4.7	2.6	2.1	3.06	Chloramine/zinc orthophosphate
2	8.4 (7.9)	5.3 (5.6)	3.1	1.31	Chloramine/phosphoric acid
3	5.1	2.5	2.6	3.12	Chlorine/chloramine switch/phosphoric acid
4	8.3	7.0	1.3	0.49	Chloramine/no inhibitor
5	3.8(3.6)	3.9	0	2.98	Low chloramine/phosphoric ace
6	5.4	3.4	2.0	2.29	High chloramine/phosphoric acid
7	15.5	4.5	11.0	2.66	Chloramine (control)

There was no relationship found between dissolved phosphate in the water and phosphorous content of the scale. Furthermore, particulate Pb showed no relationship to either PO_4 in water or P content of the scale. The only consistent trend was a decrease in dissolved Pb in the water with an increase in dissolved PO_4 in the water (Figure C.99)

Comparing scale chemistry to Pb in the water, no trends were found for the period after stabilization. Particulate Pb in the early stages of running the loops does decrease with increasing Mn content of the scale (Figure C.100), indicating that high Mn imparts a greater physical stability to the scale.

Scanning electron microscopy evaluation of scale chemistry and mineralogy

Selected samples from the pipe loops were examined by scanning electron microscopy (SEM) for information about the morphology of scale minerals and semi-quantitative chemical composition. The dominant minerals in scale Layer 1 are plattnerite and pyromorphite. SEM images of these are shown in Figures C.101 and C.102.

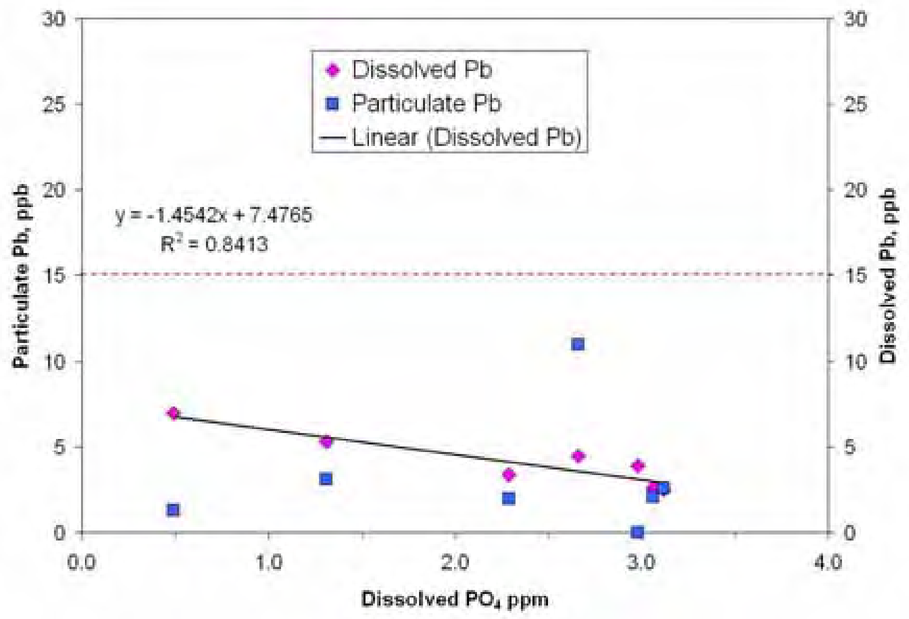


Figure C.99 Pb in water after stabilization compared to PO_4 levels. The regression line is for dissolved Pb; the correlation coefficient indicates that dissolved PO_4 explains 84% of the variation in dissolved Pb.

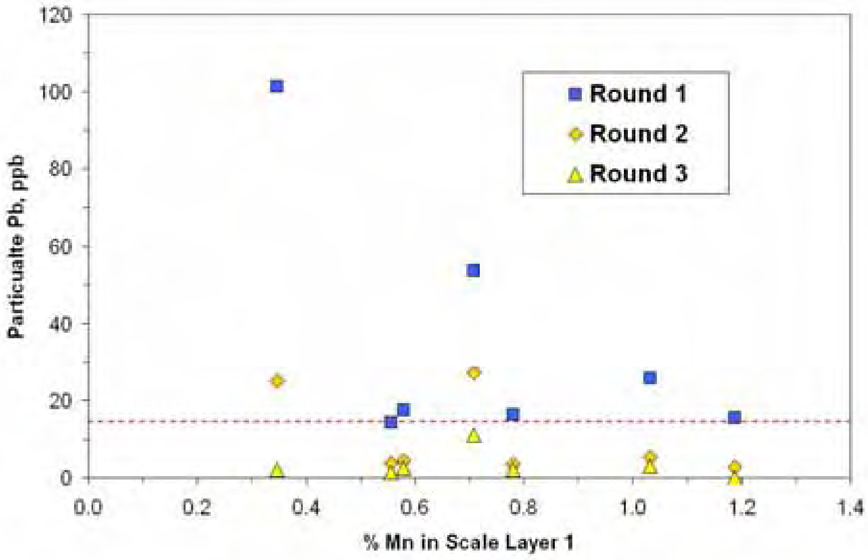


Figure C.100 Prior to stabilization, particulate Pb decreases sharply with elevated Mn in the scale. This effect disappears by round 3 of loop removal.

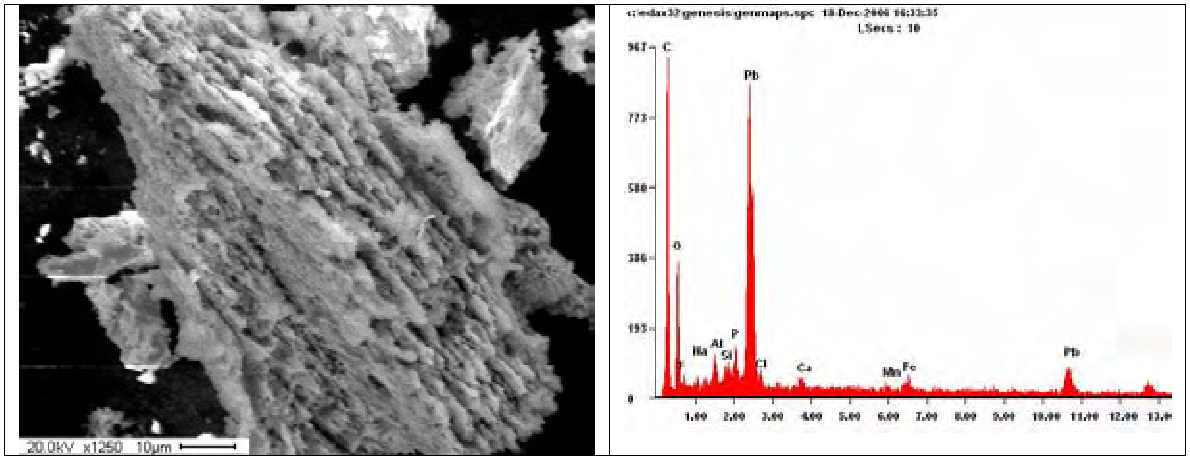


Figure C.101 SEM image of top of scale layer 1 from pipe segment 10_PP12B1 from Rack 5. Highly porous Pb oxide, shown in x-ray to be plattnerite, mixed with lesser pyromorphite and a small amount of Fe and Mn. High C is an artifact from the mounting tape.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

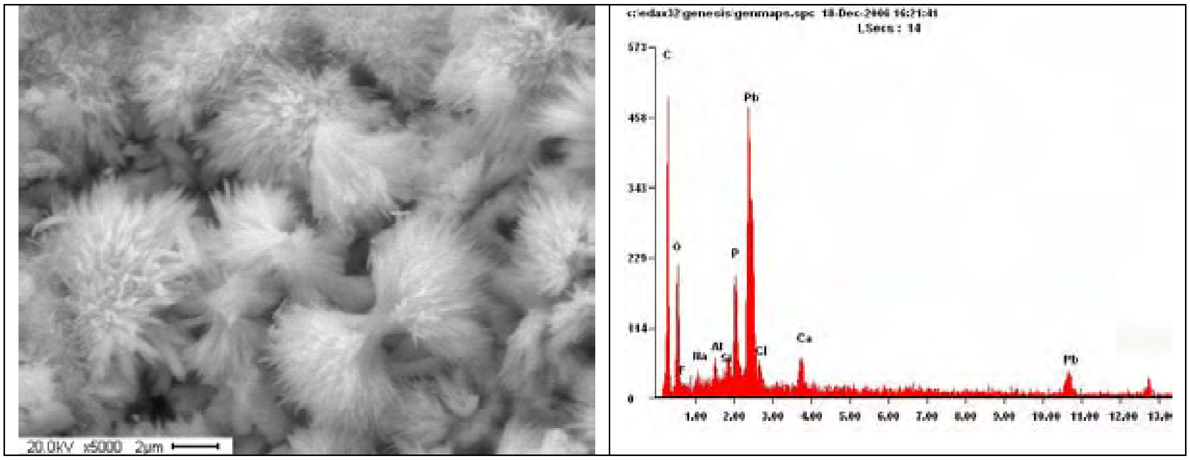


Figure C.102 SEM image of base of scale layer 1 from pipe segment 10_PP12B1 from Rack 5. Radiating sprays of needle-shaped pyromorphite indicate rapid precipitation. In the energy dispersive scan, Ca, Cl, and P are present, and are likely incorporated in the pyromorphite structure. Fe and Mn are absent from this part of the layer.

Equilibrium chemical models of scale and water chemistry

Simulations of the interaction between the scale minerals and the water in the pipe loops were run using the equilibrium-speciation functions of the PHREEQC program (ref). For input, average water chemistry parameters for Aqueduct finished water were used for major cations and anions, as given in Table C.29. Other parameters, such as dissolved Pb, were taken from the pipe loop data.

Table C.29
Summary of water quality data from Washington Aqueduct for 2006
(source: annual water quality report)

	Parameter	**°C**	**Ppm (as $CaCO_3$)**	**ppm**	**ppm**	**Ppm**	**ppm**	**ppm**	**ppb**	**ppm**	**ppm**	**ppb**
Station	pH	T	alk	Cl	PO_4	SO_4	Ca	Mg	Mn	K	Na	V
Dalecarlia	7.7	18.3	83	28	2.46	48	42	8	3.7	2.8	12.6	0.6
McMillan	7.7	16.7	70	28	2.47	50	49	8	1.3	2.9	15.0	b.d.

The results show that the water in the pipe loops is everywhere strongly supersaturated with a variety of phosphate minerals. The greatest degree of supersaturation was found for Cl-pyromorphite and F-apatite. The Pb carbonate and oxide minerals are all undersaturated, which indicates a tendency to replace them with the phosphates (Figure C.103). Thus one prediction that can be made is that there will be a gradual conversion of the minerals in surface scale layers to phosphates. Another observation is that in the presence of chlorine, the Pb oxide plattnerite is close to saturation, whereas in the presence of chloramine, it is strongly undersaturated. Therefore the switch from chlorine to chloramine disinfection will destablilize the abundant plattnerite in the scales.

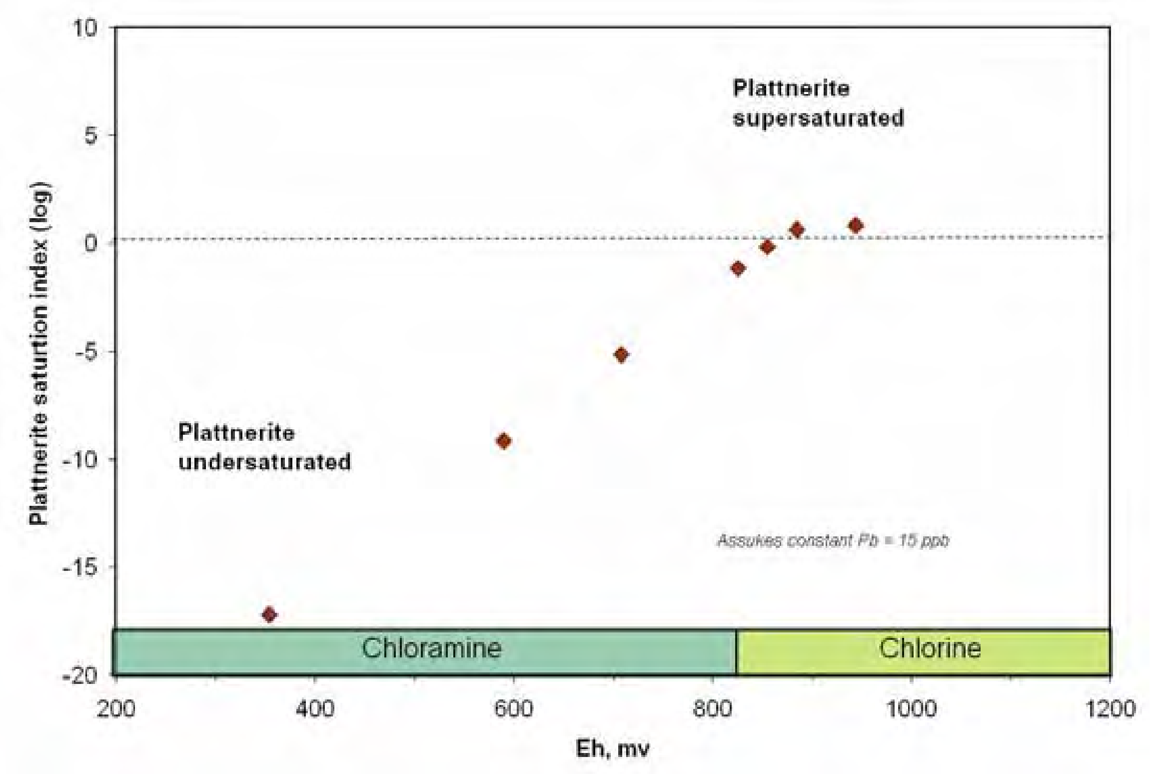


Figure C.103 Relationship of plattnerite solubility to oxidation state of the water for Washington Aqueduct finished water with 15 ppb Pb. Plattnerite is unstable in the presence of chloramine.

Another observation is that, in the presence of chlorine, a host of Mn oxides is strongly supersaturated, whereas in the presence of chloramine, the scales are undersaturated with all Mn oxides except manganite, MnOOH, which is very slightly supersaturated (Figure C.104). Considering the amorphous character of the Mn oxides in the scales, it is likely that appreciable dissolution of Mn will occur during the use of chloramine disinfection, which could lead to physical destabilization of the scales.

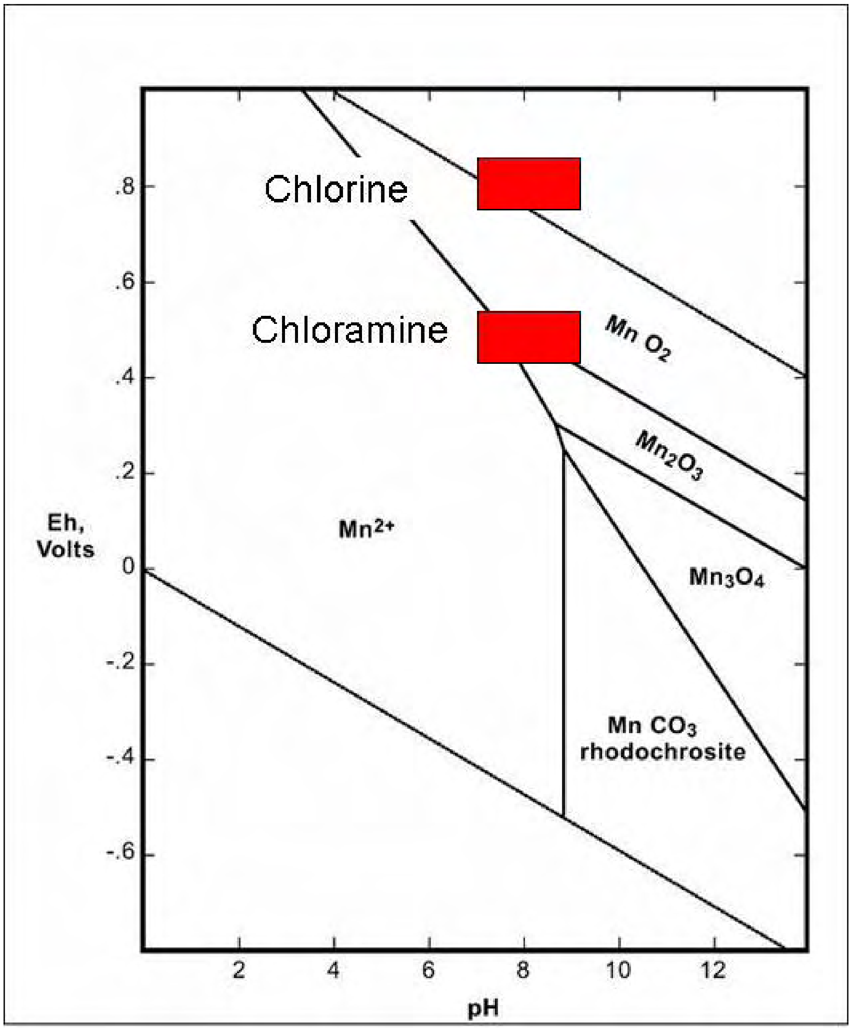


Figure C.104 Eh-pH diagram for common Mn minerals. At pH values below 8, the switch from chlorine to chloramine disinfection will destabilize Mn oxides. Eh levels for disinfectants are based on ORP measurements in the Aqueduct pipe loops. See also Vasquez, Jour. Amer. Water Works Assn. 2006, v. 98, p. 144.

Thus a change from chlorine to chloramine in the distribution system is likely to increase soluble Pb by destabilizing plattnerite and may also increase particulate Pb by destabilizing Mn oxides.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

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APPENDIX D

METALLURGICAL ANALYSIS OF FAUCET COMPONENTS FROM PORTLAND WATER BUREAU FAUCET STUDY

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table D.1
Elemental Analysis of PWB Faucets 1 and 2 Duplicate (Highest Lead Release)

Faucet Part	Elemental Percentage						
	Copper	Lead	Tin	Bismuth	Nickel	Selenium	Zinc
Cold Water Fitting	58.50	1.95	n.a.	n.a.	n.a.	n.a.	n.a.
Cold Water Tube	n.a.– flexible stainless steel tube						
Valve Body	58.23	1.89	0.12	<0.01	0.09	<0.01	38.9
Spout Receiver	57.21	2.96	0.23	<0.01	0.14	<0.01	38.9
Spout	69.09	0.01	0.01	<0.01	0.03	<0.01	30.8

Notes: na – not analyzed

Table D.2
Elemental Analysis of PWB Faucet 3 Duplicate (Lowest Lead Release)

Faucet Part	Elemental Percentage						
	Copper	Lead	Tin	Bismuth	Nickel	Selenium	Zinc
Cold Water Fitting	57.93	2.70	n.a.	n.a.	n.a.	n.a.	n.a.
Cold Water Tube	n.a. – flexible stainless steel tube						
Valve Body	57.53	1.86	0.17	<0.01	0.11	<0.01	38.8
Spout Receiver	57.40	1.83	0.17	<0.01	0.11	<0.01	39.3
Spout	63.53	<0.01	<0.01	<0.01	0.02	<0.01	35.9

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table D.3
Elemental Analysis of PWB Faucet 4 Duplicate (Envirobrass)

Faucet Part	Elemental Percentage						
	Copper	**Lead**	**Tin**	**Bismuth**	**Nickel**	**Selenium**	**Zinc**
Cold Water Fitting	87.36	0.10	4.67	1.80	0.44	0.45	4.81
Cold Water Tube	99.77	<0.01	n.a.	n.a.	n.a.	n.a.	n.a.
Valve Body	89.49	0.07	4.54	1.75	0.09	0.01	3.80
Spout Receiver	89.57	0.07	4.39	1.62	0.17	0.01	3.84
Spout	69.05	<0.01	0.06	<0.01	0.04	<0.01	30.2

Notes: n.a. = not analyzed

TableD.4
Elemental Analysis of PWB Faucet 5 Duplicate (Mid-Range Lead Release)

Faucet Part	Elemental Percentage						
	Copper	**Lead**	**Tin**	**Bismuth**	**Nickel**	**Selenium**	**Zinc**
Cold Water Fitting	58.05	3.38	n.a.	n.a.	n.a.	n.a.	n.a.
Cold Water Tube	99.92	<0.01	n.a.	n.a.	n.a.	n.a.	n.a.
Lower Valve Body	57.84	2.82	0.69	<0.01	0.28	<0.01	37.6
Upper Valve Body	57.92	2.46	0.80	<0.01	0.30	<0.01	37.1
Spout Receiver	57.53	1.76	0.34	<0.01	0.13	<0.01	39.4
Spout	65.01	<0.01	0.05	<0.01	0.02	<0.01	34.7

Notes: n.a. = not analyzed

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table D.5
Elemental Analysis of PWB Faucet 6 Duplicate (California Proposition 65)

Faucet Part	Elemental Percentage						
	Copper	**Lead**	**Tin**	**Bismuth**	**Nickel**	**Selenium**	**Zinc**
Cold Water Fitting	57.18	3.43	n.a.	n.a.	n.a.	n.a.	n.a.
Cold Water Tube	99.93	<0.01	n.a.	n.a.	n.a.	n.a.	n.a.
Lower Valve Body	56.93	3.39	0.82	<0.01	0.33	<0.01	36.4
Upper Valve Body	56.90	3.30	0.86	<0.01	0.35	<0.01	36.9
Spout Receiver	59.22	1.91	0.23	<0.01	0.06	<0.01	38.4
Spout	64.86	0.07	0.13	<0.01	0.03	<0.01	34.2

Notes: n.a. = not analyzed

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

APPENDIX E

MINERALOGY RESULTS OF BRASS RESIDENTIAL WATER METERS

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

MINERALOGY RESULTS OF BRASS RESIDENTIAL WATER METERS

An analysis was conducted to determine any potential differences in the metal composition between the exterior and interior of used SPU water meters. This analysis was conducted prior to installation of the water meters that would be ultimately used for the main project. The meters used for this side analysis originated from a set of old meters of varying indeterminate ages that had been deemed non-functional for various reasons, though primarily because most were leaking.

A metal shaving file was first used to remove surface corrosion from a small portion of the meter exterior. Afterwards, filing continued to obtain metal shavings of the exposed bare metal. The meters were then partially dismantled to expose the meter interior in order to obtain metal shavings there. The collected shavings were acid digested and analyzed in the same manner reported in the main report. Results of the analysis are shown in Table E.1. Only Pb, Cu, and Zn were analyzed for these meters since the other elements were not as critical or would not be present.

In general, Pb concentrations generally varied by 0.4 to 1.0% between the two sides for the meters, with no clear indication which side would have more Pb, even among the four meters from the same manufacturer. The exception was Meter 11, where the difference in Pb concentrations was 2.1%. However, this meter was from Manufacturer E, which was not included in the test rig. The results of this side analysis indicate that the interior Pb composition of the meters ultimately used in the test rig would not vary substantially from the exterior results that were obtained.

The Cu and Zn concentrations between the meter interiors and exteriors were also found to vary slightly with no clear indication that one side had more or less Cu or Zn than the other. Meter 11 from Manufacturer E was found to have a very large difference in Zn concentrations between nutating disk and the meter exterior. Again, further analysis of this difference was not conducted since this manufacturer was not in the group of meters that were ultimately used in the test rig.

Table E.1
Comparison of Residential Water Meter Interior and Exterior Metal Compositions

Meter	Manufacturer	Shaving Location	Element (%)			
			Pb	Cu	Zn	Other
7	B	Exterior	6.5	78.9	7.2	7.3
		Chamber Interior	7.1	81.1	7.9	3.9
8	B	Exterior	7.0	82.7	7.5	2.9
		Chamber Interior	6.6	81.7	6.7	5.1
9	B	Exterior	6.0	75.5	6.6	11.9
		Chamber Interior	6.5	77.1	7.5	8.9
10	B	Exterior	7.0	79.6	8.7	4.8
		Chamber Interior	6.4	82.0	8.0	3.6
11	E	Exterior	3.4	88.4	1.2	7.1
		Nutating disk	5.5	75.9	10.8	7.7
12	A	Exterior	6.2	80.7	8.2	4.8
		Chamber Interior	7.2	78.1	8.7	6.1
13	D	Exterior	N.A.	N.A.	N.A.	N.A.
		Chamber Interior	3.0	84.1	2.5	10.4

N.A. = not analyzed

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

APPENDIX F

FIELD EVALUATIONS OF LEAD SOURCE CONTRIBUTIONS

FIELD EVALUATIONS OF LEAD SOURCE CONTRIBUTIONS

INTRODUCTION

Field evaluations of the contribution of lead sources in service and premise piping and the impact of replacing these sources on lead levels measured at the tap were conducted at several utility locations. The overall objectives of the field monitoring activities were to:

- Identify sources of lead in service and premise plumbing and assess the relative contribution of these sources in relation to lead levels at the tap, and
- Develop best management practices for partial lead service line replacements (LSLRs) in order to reduce lead spikes.

To accomplish these objectives, the following data collection activities were completed:

- Lead service line replacement (LSLR) - Assess the relative contribution of lead sources to lead levels at the tap prior to and after partial or full LSLR,
- Faucet replacement - Assess the relative contribution of lead sources to lead levels at the tap prior to and after faucet replacement, and
- LSLR pipe cutting techniques - Compare differences in lead levels during and after partial LSLR from sites utilizing different cutting techniques.

Field monitoring activities were conducted at the Madison Water Department, Madison, Wisconsin; Boston Water and Sewer Commission (BWSC), Boston, MA; District of Columbia Water and Sewer Authority (DCWASA), Washington, DC; Toronto Water Department, Toronto, Ontario; Framingham Water Department, Framingham, MA; and the Metropolitan Water District (MWD), Hartford, CT.

LEAD SERVICE LINE REPLACEMENT

Lead service line replacements (LSLR) and associated water quality monitoring were completed at Madison, Boston, DCWASA, and Toronto. The following section describes the overall site selection process and sampling protocol, followed by specific information and results from each utility location.

Site Selection

At each location, residential sites with lead service lines were selected according to the following criteria:

- Site was part of utilities' scheduled LSL replacement program.
- Site did not have any home water treatment systems (i.e. water softener, home reverse osmosis units, kitchen tap filter, etc.)
- Site was located in part of the distribution system where the water quality (especially chlorine and alkalinity) did not vary significantly over time or where the chlorine residual was routinely absent.
- Site was not located along a dead-end water main.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

- Site did not have double service lines or was served by a service line header.
- The site service line or premise plumbing did not have any water leaks.
- Homeowner agreed not to use water during the daytime stagnation period.

A premise piping survey was conducted at each site prior to sampling to determine the length, diameter, and type of pipe between the kitchen faucet and the beginning and end of the LSL. These data were used to calculate the water volume that must pass through the kitchen faucet to reach water in contact with the LSL during the stagnation period.

Sampling Protocols

Water samples were collected at the kitchen tap before LSLR, the day of the replacement, and several times after LSLR replacement (24 hours, 2 days, 3 days, 1 month, and 2 months after). Sampling consisted of an initial flushed sample (15 minutes plus), followed by a series of sequential samples collected after the water was allowed to stagnate for a minimum of 6 hours. Initial samples collected were 125mL and 250mL in volume, followed by one liter samples. The number of samples collected was calculated based on the site survey information. Table F.1 lists the samples collected. Total and dissolved lead were analyzed on all samples, with filtration of samples occurring in the field, or shortly thereafter. The kitchen faucet remained open for the entire sampling duration, as opposed to opening and closing the faucet between samples. For all samples, any aerator on the kitchen faucet remained attached during sampling. Field temperature, pH, conductivity or TDS, total and free chlorine measurements were taken during each sampling event. In addition, at some utility locations, alkalinity and major cation/anions were measured on selected samples.

Table F.1
Samples Collected Before and After LSLR Evaluation

Sample No.	Volume	Conditions
1	1 L	Flushed, before stagnation
2	125 mL	After stagnation
3	125 mL	After stagnation
4	250 mL	After stagnation
5	250 mL	After stagnation
6	250 mL	After stagnation
7- 15	1 L	After stagnation

Madison Water Utility

Madison Water Utility provides drinking water to the City of Madison, Wisconsin and surrounding areas. The source of supply is groundwater from a deep sandstone aquifer that is pumped from 24 wells that range from 500 to 1130 feet deep. Water quality characteristics vary at each well and Table F.2 lists characteristic values for several parameters that are typically measured (Madison Water Utility, 2006).

Water treatment consists of chlorine addition to achieve 0.2 mg/L free chlorine and fluoride addition to achieve 1.1 mg/L. This chemical addition is performed at each well house.

Site Information and Sample Collection

Full lead service line replacements occurred at four sites, labeled M1, M2, M3, and M4. The interior volume contained in the premise piping and the service line from each location was calculated, and is displayed in Table F.3.

Table F.2
General Water Quality Characteristics in Madison, Wisconsin

Parameter	Typical Value
Temperature	About 15 deg. C
pH	7.4 to 7.8
Total Dissolved Solids	290 to 576 mg/L
Calcium	160 to 235 mg/L as $CaCO_3$
Magnesium	140 to 226 mg/L as $CaCO_3$
Alkalinity	267 to 334 mg/L as $CaCO_3$
Dissolved Inorganic Carbonate	About 455 mg/L as $CaCO_3$ (55 mg/L as C)
Chlorides	2.4 to 56 mg/L
Sulfates	6.6 to 43 mg/L
Iron	0 to 540 µg/L
Manganese	0.3 to 88 µg/L

Table F.3
Site Survey Information for Madison Lead Service Line Replacement Sites

Site No.	Location	Volume, L
M-1	Kitchen faucet to meter	5.1
	Service	2.9
	Total	**7.9**
M-2	Kitchen faucet to meter	3.2
	Service	3.7
	Total	**6.9**
M-3	Kitchen faucet to meter	4.1
	Service	3.6
	Total	**7.7**
M-4	Kitchen faucet to meter	4.1
	Service	2.8
	Total	**6.9**

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Results

Water Quality. One flowing water sample per site was taken just before the lead service line was replaced. The sample was analyzed for nitrate+nitrite, potassium, silica, sulfate and total organic carbon. The ranges of concentrations found are shown in Table F.4.

Table F.4
General Water Quality From Flowing Water Samples at Madison

Parameter	Minimum	Maximum
Aluminum, ug/L	n.d. (1)	n.d. (1)
Nitrate+Nitrite, mg/L	0.3	1.74
Potassium, mg/L	n.d.(1)	1
Silica, mg/L	13	17
Sulfate, mg/L	18	38.2
Total Organic, mg/L	0.48	0.67

(1) nd = non-detect

Because water is very hard in Madison, the majority of homes have water softeners on the hot water line to protect the hot water heater from scaling. Some homes soften both hot and cold water. In sampling for lead and copper, it was desired to have no alteration to the water on-site, so the hardness of the cold water at the sample tap was tested with a “Hardness test strip” during the site inspection. The total hardness was expected to be around 300 mg/L as $CaCO_3$ or higher. If the test strip indicated that the cold water was softened, the site was rejected as a sampling site.

The test strips indicated that all four sites had unsoftened cold water at the sample tap. However, the M-2 site test results for calcium, magnesium, sodium, and chloride from a flowing water sample taken just before the lead service line replacement indicated that the water was softened. The laboratory confirmed the results (sodium and chloride will be elevated in softened water because most home softening systems are ion exchange resins where calcium ions are replaced by sodium and sodium chloride is used to regenerate the resin.) Another sample was taken later on to confirm the results. That sample showed unsoftened cold water at the sample tap. Table F.5 shows all data related to water softening.

Table F.5
Softening Data from Madison

Parameter	Units	M-1	M-2	M-3	M-4	M-2 re-test
Calcium	mg/L	69.9	0.7	70.0	67.0	74.4
Magnesium	mg/L	39.6	0.4	40.6	39.3	39.3
Sodium	mg/L	8.4	171	10.3	8.8	
Chloride	mg/L	15.0	30.6	20.2	18.9	

One explanation for this result at Site M-2 is that softened hot water was sampled by mistake since the sample tap was a hot/cold water mixing faucet. If this occurred only in the one flowing sample where calcium, etc. were measured by a laboratory, then the remaining data for lead during the other sampling events was assumed to still be valid. The lead data in this study were examined with this problem in mind.

Iron and manganese scales on the pipe wall are thought to play an important role in the release of lead particulates in Madison (see Madison Case Study in Appendix B). The iron and manganese concentrations vary throughout the distribution system and over time depending on which of the twenty-four water sources are providing water at any given time and location. Table F.6 shows the iron and manganese concentrations at the four test sites as found in a flowing water sample taken just before lead service line replacement.

Chlorine concentration, conductivity, pH, and temperature were performed on-site and Table F.7 to F.10 shows the results of those tests. For one flowing water sample taken immediately before the lead service line was replaced, oxidation-reduction potential measurements were also made on-site. Figure F.1 displays the measurements.

Total zinc, copper, and heterotrophic plate count were measured on four stagnation water samples taken per site. Table F.11 lists the copper and zinc results. There were a number of laboratory and sampling errors that occurred with the HPC samples, therefore Table F.12 shows only the data where there were no observed problems in obtaining the results.

Table F.6
Iron and Manganese Levels at Madison LSLR Sites

Site	Iron (µg/L)	Manganese (µg/L)
M-1	n.d.(1)	22
M-2	n.d.(1) Detected(1)	3
M-3	n.d.(1)	43
M-4	300	24

(1) nd = non-detect.

Table F.7
Site M-1 Field Analyses

Relation to Lead Service Line Replacement	pH	Temperature, °C	Free Chlorine, mg/L	Total Chlorine, mg/L	Conductivity, umhos/cm
Before	7.20	23.2	0.10	0.10	622
Immediately Before	7.18	17.6	0.05	0.04	827
1 Day After	7.20	21.1	0.02	0.02	981
2 Days After	7.22	22.0	0.03	0.04	740
3 Days After	7.06	21.1	0.04	0.04	729
1 Month After	7.35	20.1	0.01	0.01	737
2 Month After	7.29	19.0	0.05	0.05	675

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.8
Site M-2 Field Analyses

Relation to Lead Service Line Replacement	pH	Temperature, °C	Free Chlorine, mg/L	Total Chlorine, mg/L	Conductivity, umhos/cm
Before	7.63	22.1	0.01		606
Immediately Before	7.6	19.7	0.02	0.03	703
1 Day After	7.51	20.2	0.08	0.07	719
2 Days After	7.46	20.3	0.04	0.04	694
3 Days After	7.51	19.8	0.03	0.00	703
1 Month After	7.71	19.7	0.02	0.02	764
2 Month After	7.53	17.6	0.01	0.01	664

Table F.9
Site M-3 Field Analyses

Relation to Lead Service Line Replacement	pH	Temperature, °C	Free Chlorine, mg/L	Total Chlorine, mg/L	Conductivity, umhos/cm
Before	7.18	25.6	0.04	0.05	655
Immediately Before	7.19	16.4	0.07	0.07	645
1 Day After	7.32	20.2	0.01	0.01	653
2 Days After	7.14	17.8	0.12	0.14	662
3 Days After	7.25	19.8	0.07	0.07	669
1 Month After	7.60	16.4	0.03	0.03	675
2 Month After	7.49	14.4	0.04	0.04	635

Table F.10
Site M-4 Field Analyses

Relation to Lead Service Line Replacement	pH	Temperature, °C	Free Chlorine, mg/L	Total Chlorine, mg/L	Conductivity, umhos/cm
Before	6.58	17.7	0.01	0.01	586
Immediately Before	7.22	13.6	0.07	0.07	591
1 Day After	6.97	15.1	0.06	0.07	675
2 Days After	7.10	16.1	0.01	0.01	658
3 Days After	6.47	16.6	0.05	0.05	671
1 Month After	6.69	14.1	0.20	0.22	675
2 Month After	6.72	17.3	0.01	0.01	698

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.11
Zinc and Copper Levels from Stagnation Samples – Madison

	Zinc, ug/L				**Copper, ug/L**			
	M-1	**M-2**	**M-3**	**M-4**	**M-1**	**M-2**	**M-3**	**M-4**
Before	319	16	168	258	14	107	154	155
3 Days After	1410	69	332	209	49	110	170	326
1 Month After	1420	83	217	40	72	120	65	142
2 Months After	1570	67	234	148	78	122	65	166

Table F.12
HPC Levels from Stagnation Samples – Madison

	HPC, cfu/mL			
	M-1	**M-2**	**M-3**	**M-4**
Before	21	1000	-	240
3 days after	920	-	-	78
1 month after	410	425	-	4
2 months after	700	-	315	46

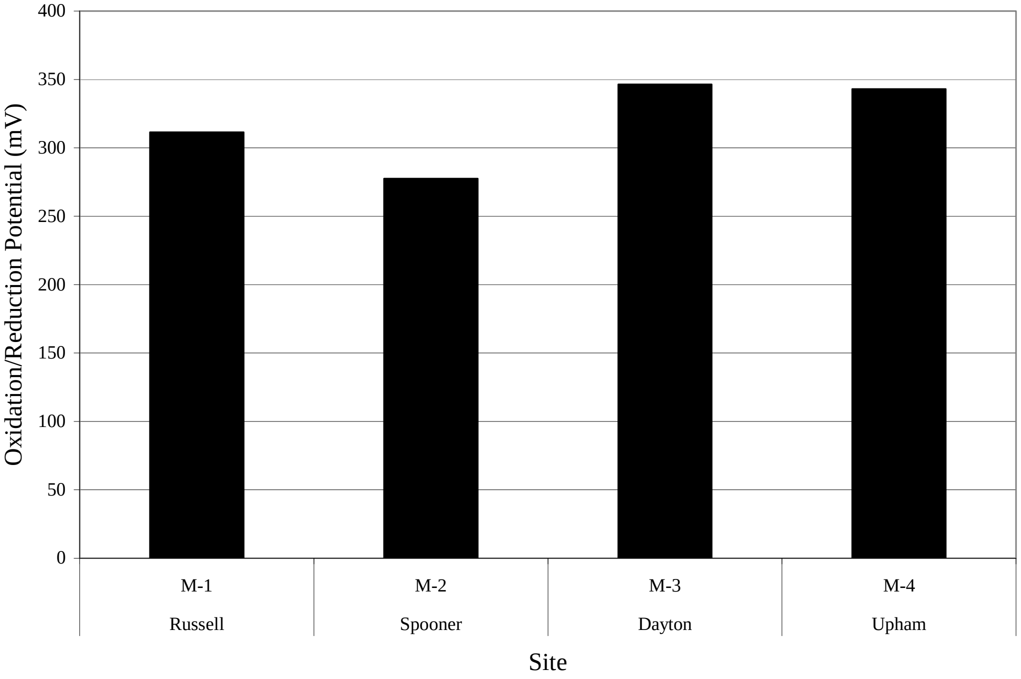


Figure F.1 Oxidation/Reduction Potential – Madison

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Lead Levels. Sequential volumes of stagnation water were obtained during six sampling events at each site. The samples were analyzed for both total and dissolved lead concentration. In this way, a profile of lead concentrations through the site's plumbing system was obtained. Figures F.2 to F.9 show these profiles for total and dissolved lead.

The first major trend in the data is that most of the lead captured in water samples at the four sites is in particulate form. This corresponds to past lead sampling results in Madison. Particulate lead appears to accumulate in the faucet area. In general, particulate lead is high around the water meter and decreases into the plumbing system. Any place in the line where particulates can accumulate become evident in the profiles such as occurs at Site M-1 at three liters into the plumbing system from the faucet (Figure F.2).

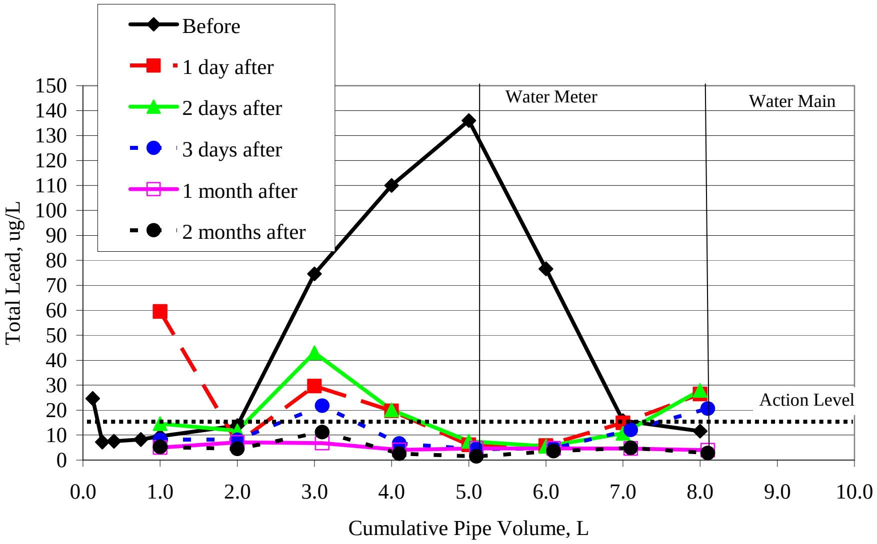


Figure F.2 M-1 Total Lead Concentration Profiles (stagnation)

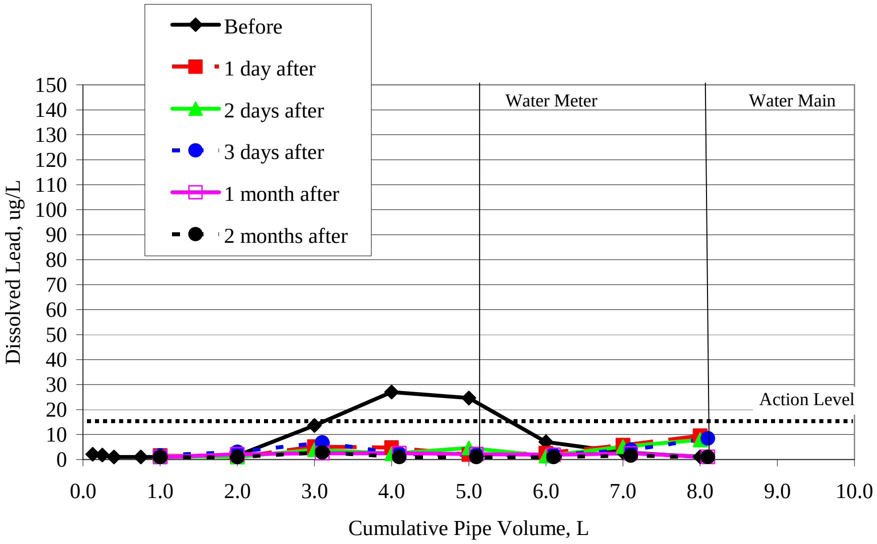


Figure F.3 M-1 Dissolved Lead Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

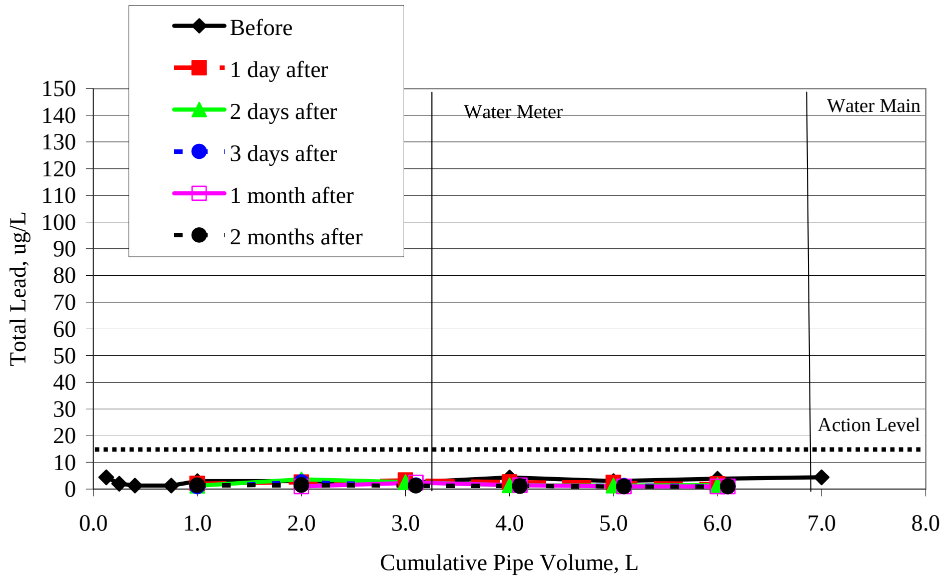


Figure F.4 M-2 Total Lead Concentration Profiles (stagnation)

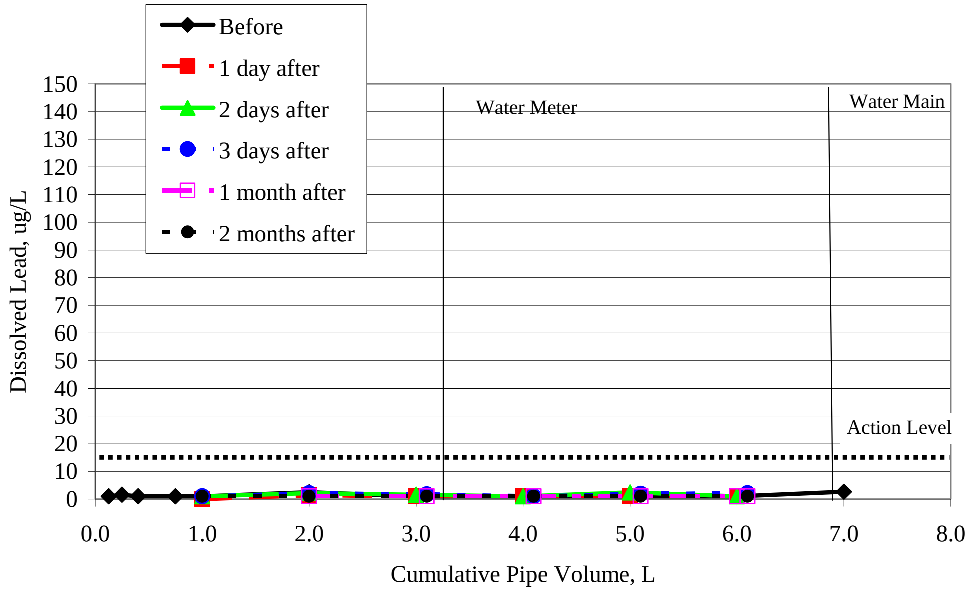


Figure F.5 M-2 Dissolved Lead Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

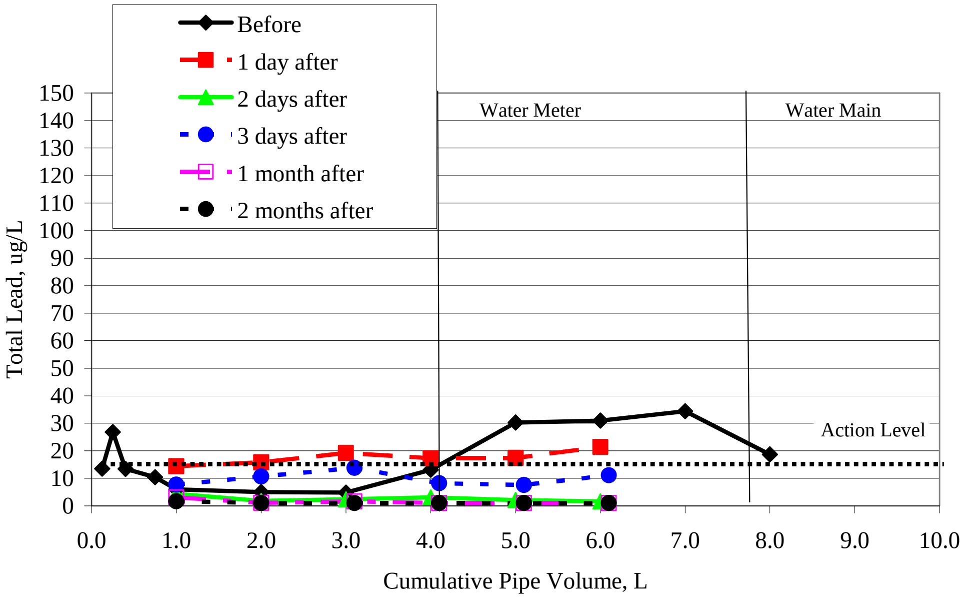


Figure F.6 M-3 Total Lead Concentration Profiles (stagnation)

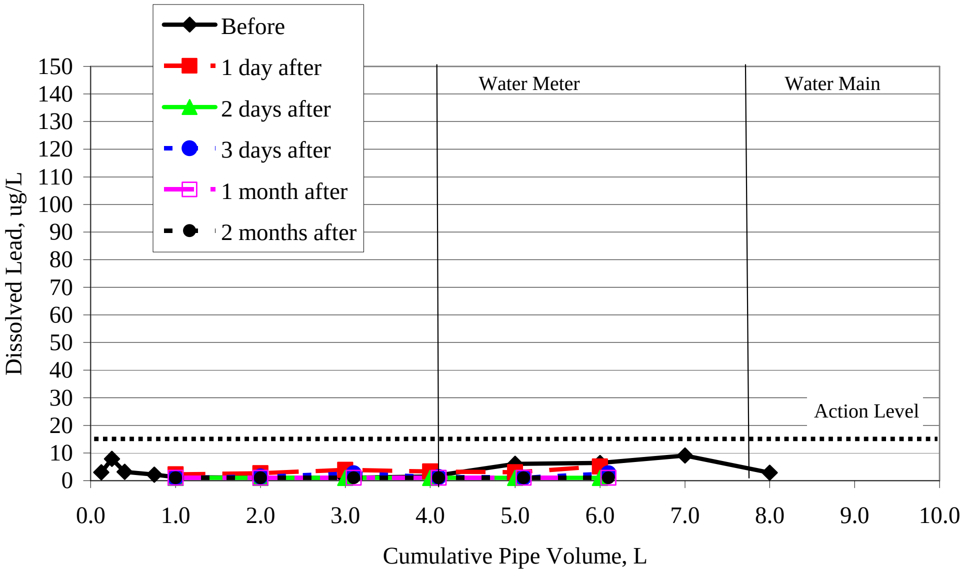


Figure F.7 M-3 Dissolved Lead Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

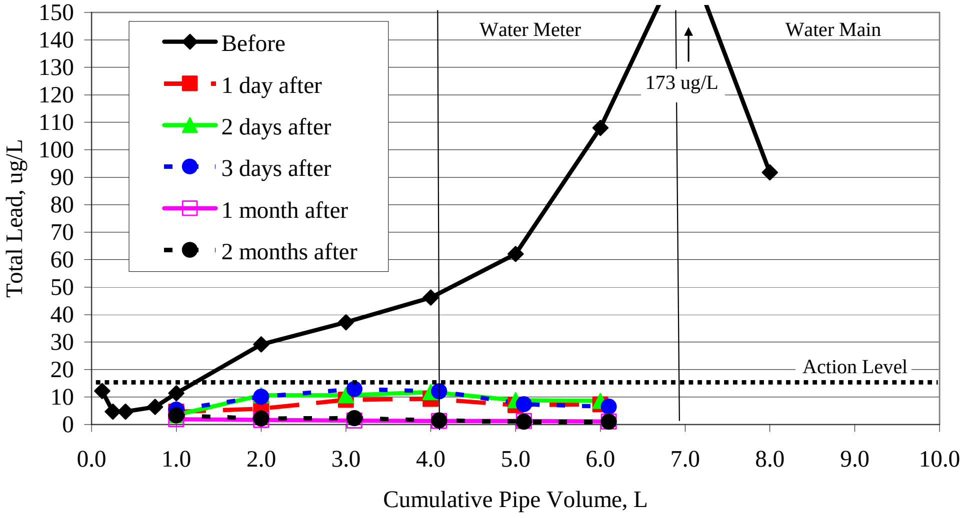


Figure F.8 M-4 Total Lead Concentration Profiles (stagnation)

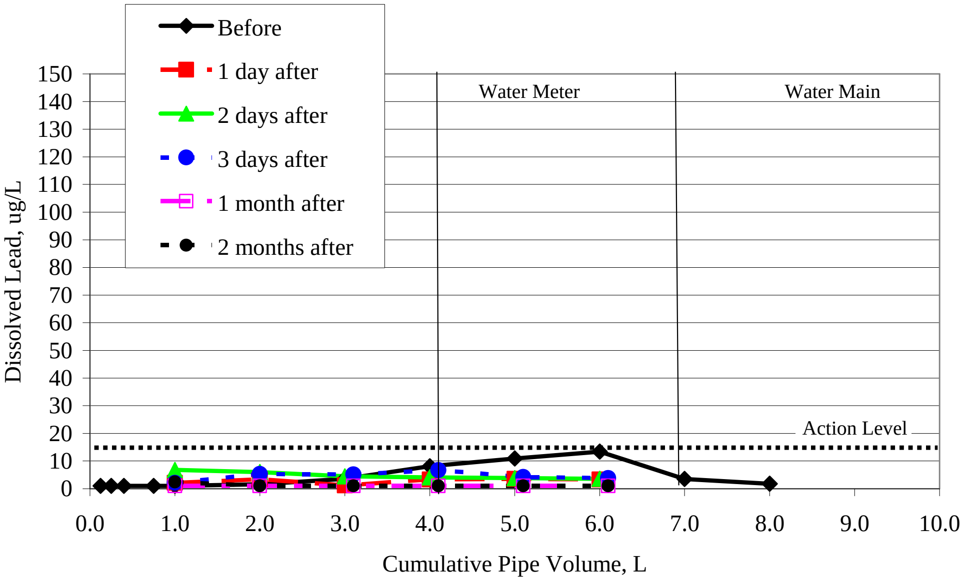


Figure F.9 M-4 Dissolved Lead Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

The M-2 site exhibited very low lead particulate concentrations and low total lead overall (Figures F.4 and F.5). This is the site where water appeared to be softened during one of three hardness tests run at the site. Manganese levels at this site were low in comparison to the other sites (Table F.6).

By the first three days after the lead service line is replaced, total and particulate lead levels were brought down to near or below the Action Level of 15 µg/L at all sites. After two months, the total and particulate lead levels were near or at the Limit of Detection of 1 µg/L.

Eight flowing water samples were taken at each site. Figures F.10 to F.13 display the results of total and dissolved lead analyses. Again it is seen that in Madison, particulate lead is the significant fraction of the total lead found in the water. Particulate lead in flowing water was near or below the Action Level of 15 µg/L before the lead service line was replaced. Just after the lead service line was replaced, the particulate lead levels jumped up. Even the M-2 site, which exhibited lower lead levels than the other sites, experienced this increase in particulates just after the lead line replacement.

Within one day of full lead service line replacement, the total and particulate lead levels in flushed samples fell to at or near the Limit of Detection at 1 µg/L. Though it appears from this data that the total lead levels in flowing water stay at the Limit of Detection, there is still a possibility of entraining randomly released lead particulates into the water.

First liter lead results measured after LSL replacement were compared to first liter results calculated from initial 125 mL and 250 mL samples collected prior to replacement. These results are shown in Figures F.14 to F.17. All sites had first liter lead levels below the action level (15 ug/L) prior to replacement. By three days after full LSL replacement, all sites exhibited lower first liter lead levels when compared to first liter results calculated before replacement. This improvement continued 1 and 2 months after replacement. There was an increase in lead measured in first liter samples 24 hours after LSL replacement at sites M-1 and M-3.

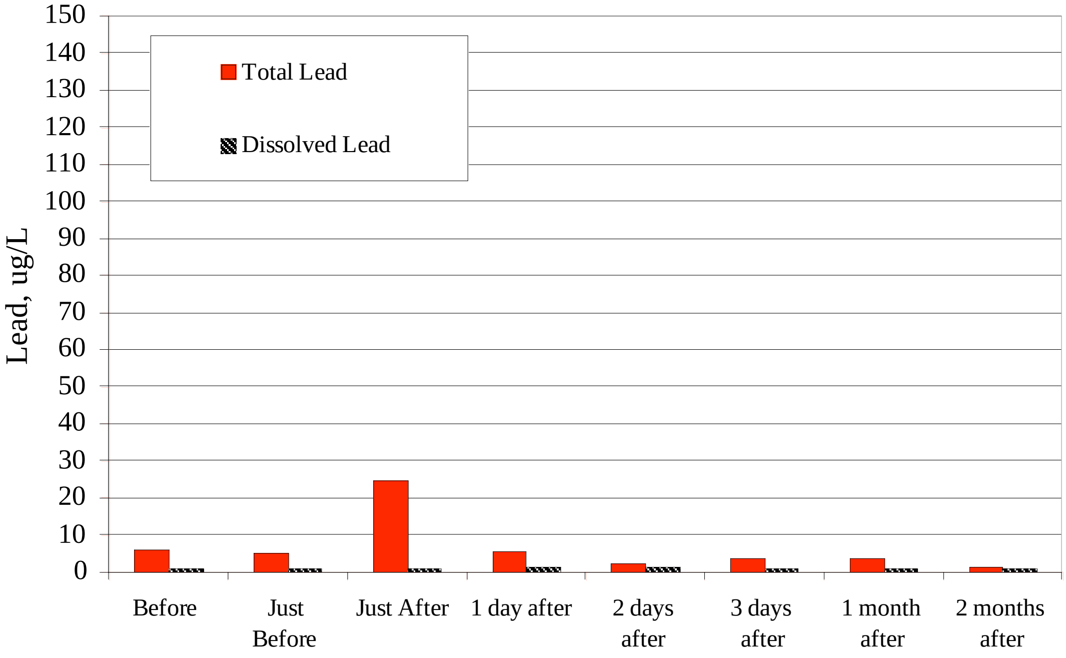


Figure F.10 M-1 Lead in Flowing Water

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

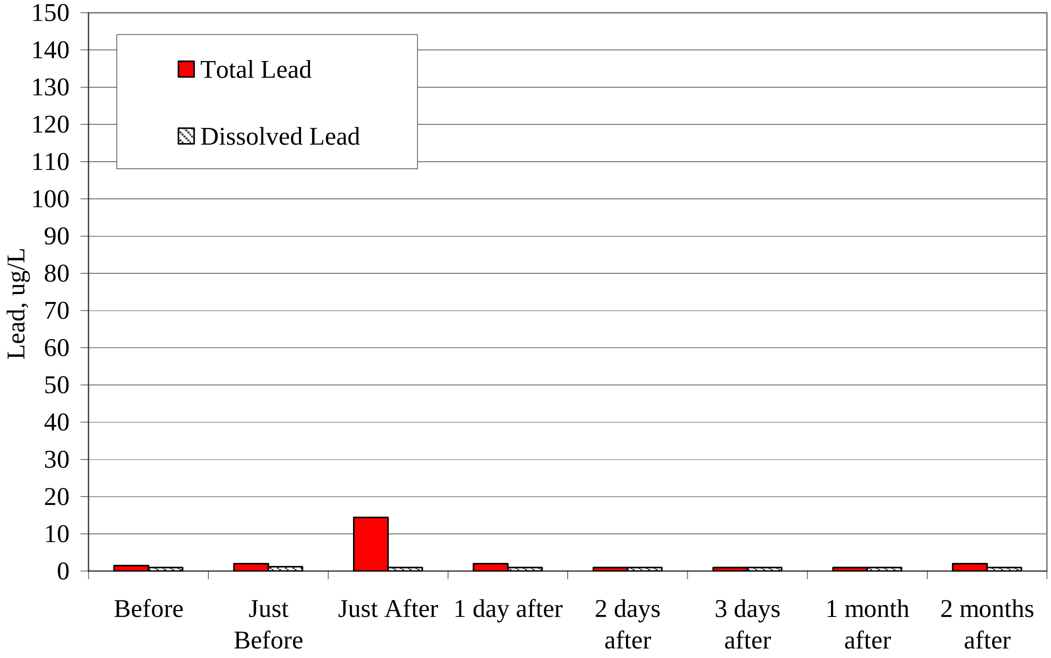


Figure F.11 M-2 Lead in Flowing Water

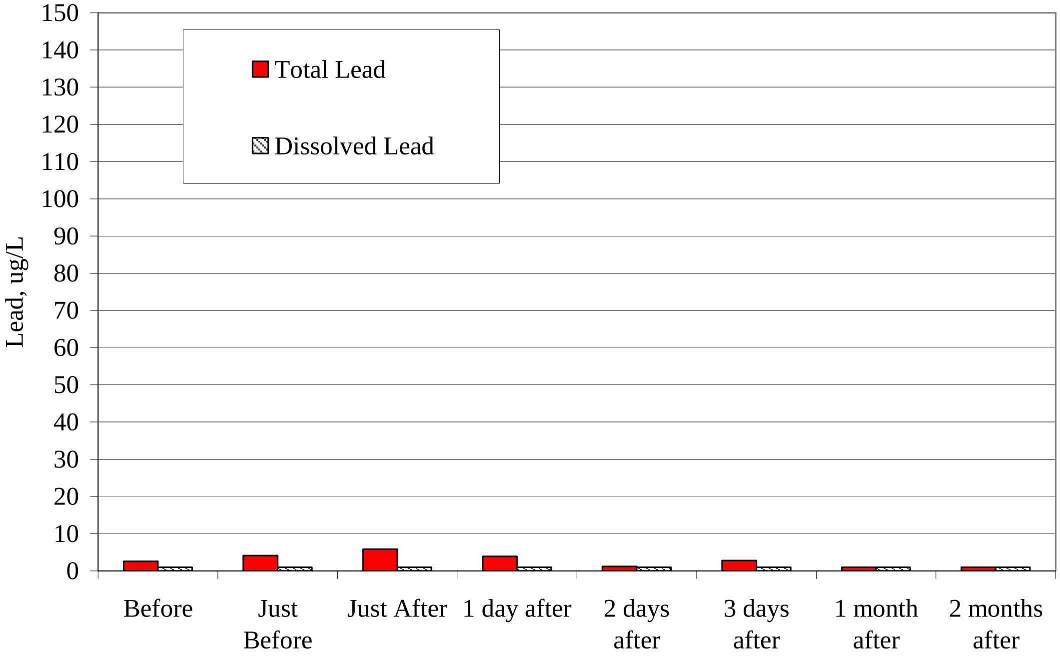


Figure F.12 M-3 Lead in Flowing Water

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

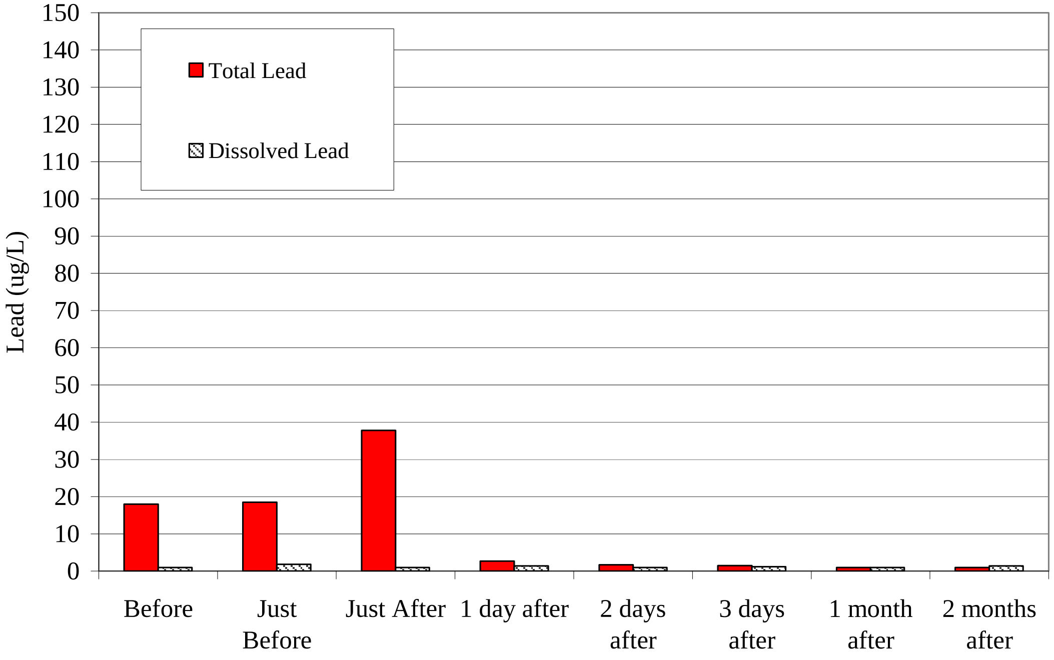


Figure F.13 M-4 Lead in Flowing Water

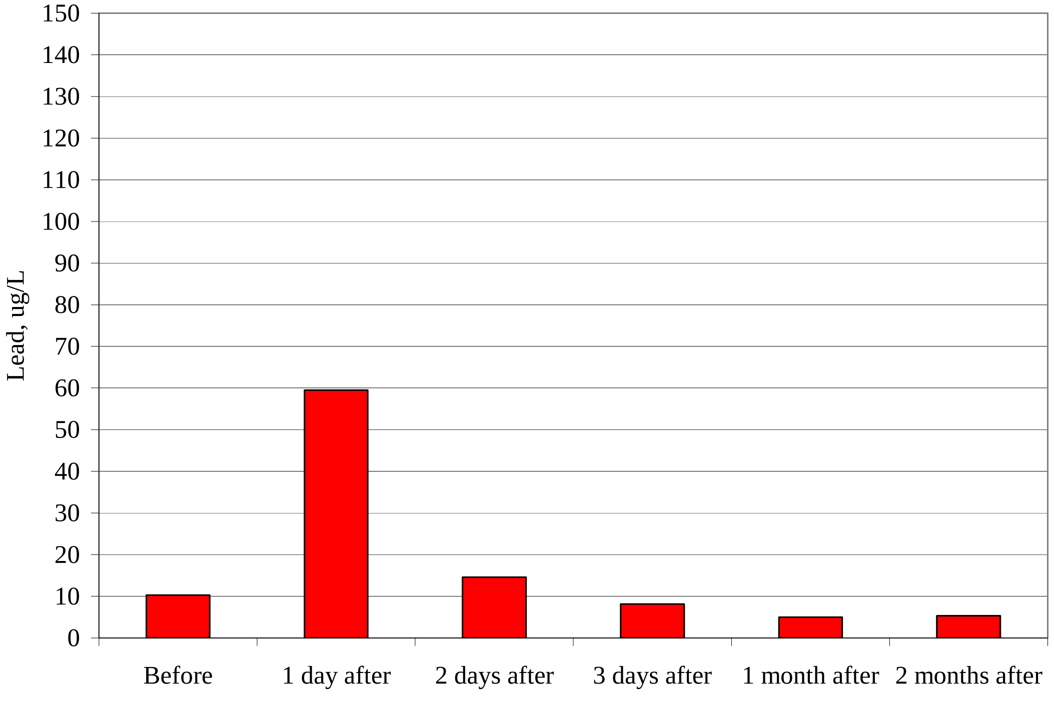


Figure F.14 M-1 First Liter Lead Levels (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

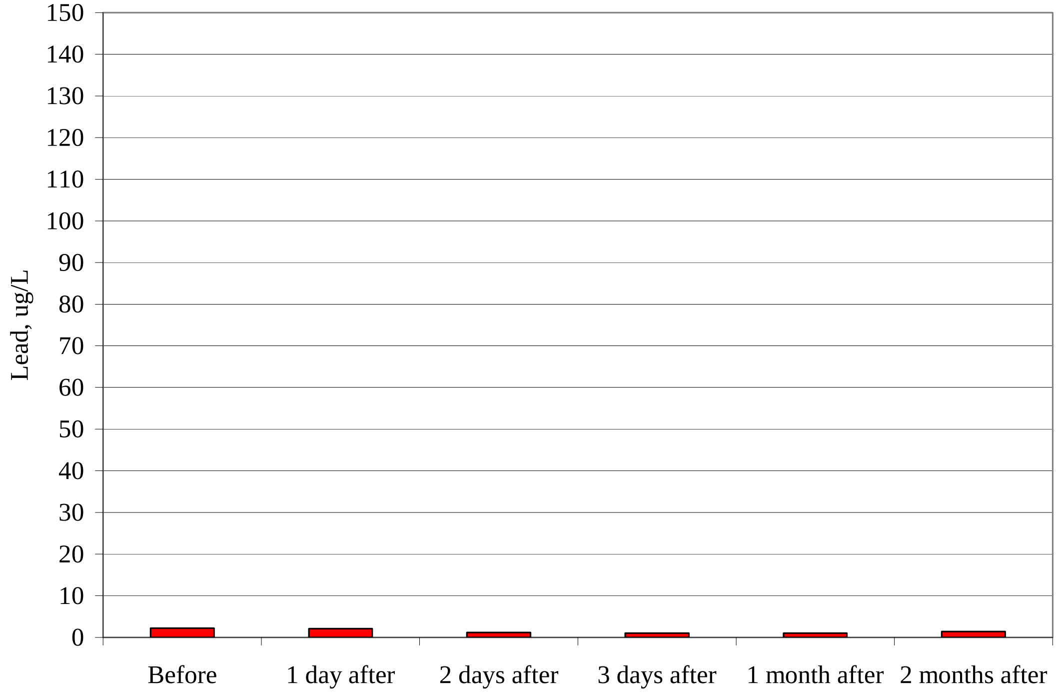


Figure F.15 M-2 First Liter Lead Levels (stagnation)

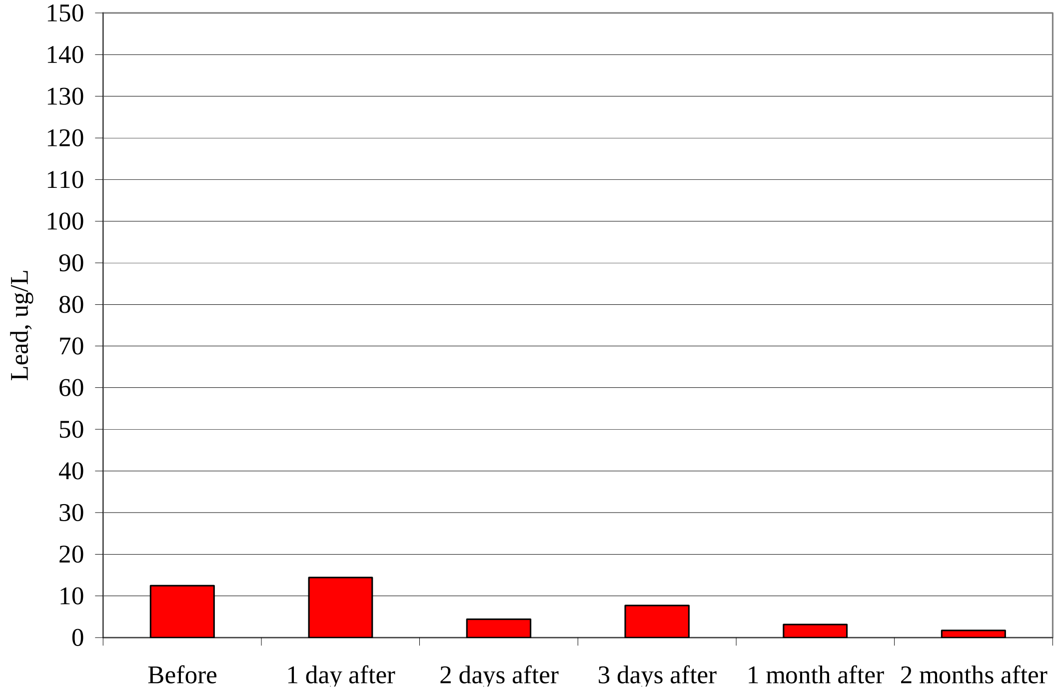


Figure F.16 M-3 First Liter Lead Levels (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

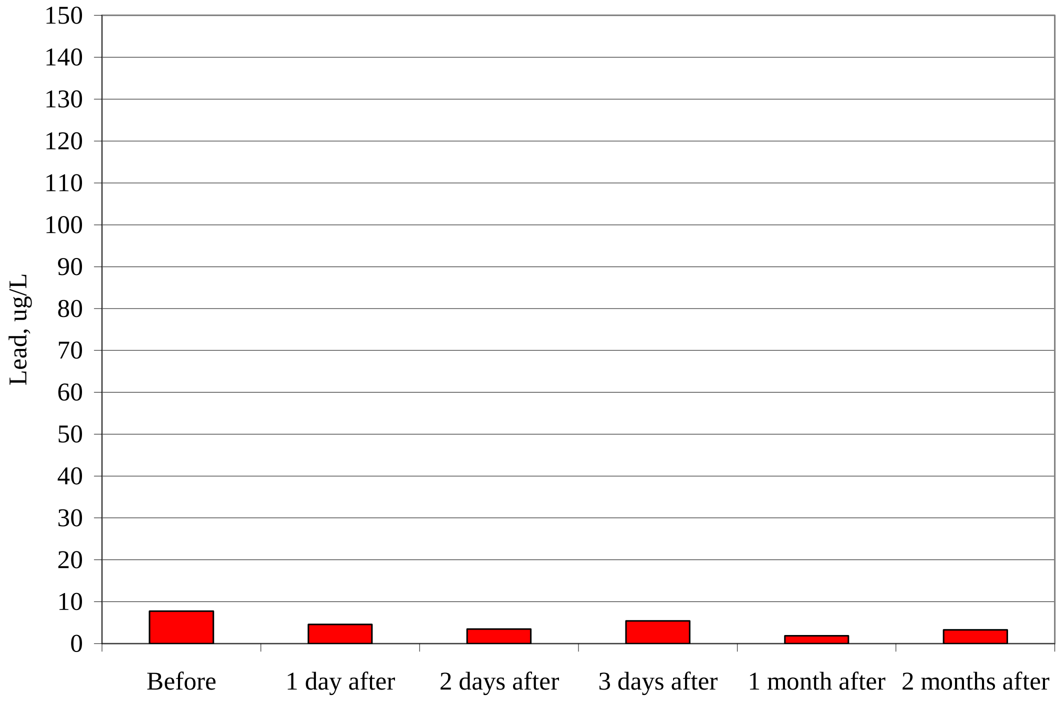


Figure F.17 M-4 First Liter Lead Levels (stagnation)

Scale Analyses. Pipe samples, which included lead service lines and attached brass fittings, were received from the four lead service replacement sites by the University of Cincinnati for scale analyses. The laboratory numbers assigned to each section of these pipes is shown in Table F.13.

Scale properties. Elemental Analysis – Lead Pipe. The total metals content of the scale scraped for analyses from lead piping specimens was in the range 50-60%, with the remaining content consisting of oxygen (O) and carbon dioxide (CO2), which are not measured in XRF. Of the metals, lead (Pb) greatly predominates at approximately 40-50% of the total. Copper (Cu) and zinc (Zn) were low in abundance, but always present. Some tin (Sn) was found as well, which indicates the presence of small amounts of brass corrosion products in the Pb scales. Other elements present in significant amounts were manganese (Mn), iron (Fe), and calcium (Ca). Mn was considerably higher than in scales from other distribution systems in this study. Table F.14 gives a summary of the elemental data for the most common components. Among the sites, M-3 was very high in Mn and Ca was high in the M-2 and M-3 samples. All scales were rich in sulfur (S).

Table F.13
Samples Received from Madison Water Utility for Scale Analyses

Street address	Laboratory number*	Description
M-1	06_PX01	Lead pipe w gooseneck connection to brass
M-1	06_PP02	Lead pipe
M-2	06_PP03	Lead pipe
M-2	06_PP04	Lead pipe
M-3	06_PP05	Lead pipe w gooseneck connection to brass
M-3	06_PP06	Lead pipe
M-3	06_PX07	Lead pipe w gooseneck connection to brass shut-off valve
M-3	06_PX08	Lead pipe w gooseneck connection to brass
M-3	06_FB09	Brass hose bib
M-4	06_PP10	Lead pipe
M-4	06_PX11	Lead pipe w gooseneck connection to brass
M-4	06_FB12	Brass faucet
M-4	06_PF13	Galvanized pipe
M-4	06_PB14	Brass fitting

* definitions for the nomenclature for the laboratory I.D. numbers can be found in Appendix G

Table F.14
Summary of Elemental Results for Scale on Lead Plumbing Components

	Water*		Elemental % in Scale						
	Pb total	Pb dissolved	Ba	Sn	Pb	Fe	Mn	Ca	S
M-1	35.4	9.1	0.00	0.02	48	0.7	2.8	0.5	0.44
M-2	3.6	2.0	0.00	0.01	48	0.7	2.7	5.4	0.29
M-3	14.7	4.4	0.15	0.01	41	2.0	14	3.5	0.26
M-4	44.1	4.7	0.01	0.18	48	0.3	0.6	0.8	0.74

*average value from sequential samples collected before LSLR

The scales were separated into layers according to ease of scraping. The top scale layer in every case was high in Fe and Mn, which decreased drastically in subsequent layers. Silica (Si) and aluminum (Al) tended to be higher in the deeper scale layers, but this was not universally true. Because Si and Al correlated well with each other, it is likely that the presence of the silicate is not from treatment, but from clay either carried through the system or attached to the outside of the pipes. Phosphorus (P) was low everywhere in contrast to systems that use phosphate treatment. Sulfur (S) was significant in all samples and very high in one sample at Upham.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scale properties. Elemental Analysis - Brass Fittings. The scales found on brass fittings from Madison, like those on the lead pipes, were quite high in Mn. Copper (Cu) was high, as expected, but was subordinate to Mn at sites M-1 and M-3 (Table F.15). Site M-3 was also very high in Ca. Appreciable Fe was present in all scales, as was Pb, which was especially high in the M-3 scales. Sulfur (S) was low compared to the Pb scales. Barium (Ba) correlated strongly with Mn. As with the lead scales, Mn and Fe were strongly concentrated in the surface layer.

Table F.15
Summary of Elemental Analyses of Scales on Brass Components

	Water*		**Elemental % in Scale**								
	Pb total	P diss	Cu	Zn	Ba	Sn	Pb	Fe	Mn	Ca	S
M-2			28.7	0.48							
Spooner	3.6	2.0			0.03	0.80	1.2	7.7	11	4.0	0.01
M-3			5.44	0.13							
Dayton	14.7	4.4			0.09	0.18	10	2.8	14	27	0.02
M-1			4.99	0.18							
Russell	35.4	9.1			0.37	0.04	0.2	6.1	52	3.1	0.02
M-			37.8	1.13							
4Upham	44.1	4.7			0.02	0.97	3.9	2.6	1.2	1.9	0.00

*average value from sequential samples collected before LSLR

Iron (galvanized) pipe. One piece of galvanized pipe was obtained from the site M-4 pipe sequence. The scale was rich in Fe and Mn, as expected, but also quite high in Pb and in Ca. Zinc (Zn) was notably low, as in all the other scales, which reflects the much greater solubility of Zn compared to Cu, Pb, and Sn. As a consequence, Zn tends to be carried through to the tap, whereas appreciable amounts of the other metals remain as scale-forming constituents.

Scale properties. Mineralogy. Mineralogically, the Madison lead specimens were dominated by cerussite ($PbCO_3$) and plattnerite (PbO_2) in the surface layers and litharge (PbO) in deeper layers. Some hydrocerussite ($Pb_3(OH)_2(CO_3)_2$) also appeared in deeper layers. Table F.16 lists the locations, average total and dissolved lead and calculated first liter lead level measured from stagnation samples collected prior to removal of the service line. Also included is a list of the most common minerals in the scale on the lead plumbing components, in order of abundance.

Table F.16
Common Minerals Found on Material Specimens at Madison Water Utility LSL Replacement Sites

	Average of All Sequential Samples		**Calculated First Liter Lead, ug/L**	**Scale minerals in layer closest to water**
Site	**Total Pb, ug/L**	**Dissolved Pb, ug/L**		
M-1	35.4	9.1	10.3	Cerussite >> plattnerite
M-2	3.6	2.0	2.2	Plattnerite > cerussite
M-3	14.7	4.4	12.5	Calcite > plattnerite ≈ cerussite ≈ litharge
M-4	44.1	4.7	7.7	Cerussite > plattnerite > litharge

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

In Table F.16 it can be seen that there may be an association of Pb releases at the tap with mineralogy. Mineralogically, the Madison lead specimens were dominated by cerussite ($PbCO_3$) and plattnerite (PbO_2) in the surface layers and litharge (PbO) in deeper layers. Some hydrocerussite ($Pb_3(OH)_2(CO_3)_2$) also appeared in deeper layers. This difference accords with the greater solubility for cerussite. Note, however, that dissolved Pb is somewhat similar for all localities whereas particulate Pb is showing the major relationship to mineralogy. This discrepancy suggests that the correlation of Pb release to cerussite may be driven by another parameter. Figure F.18 shows the association of mineralogy with Pb releases.

Correlation with Water Quality. Correlations of lead measured in the water prior to lead service line replacement with the various elemental and mineralogical compositions of the scale were completed. A correlation matrix was constructed using all of the water chemistry and scale chemistry parameters, averaged by site. The most significant correlations are shown in Table F.17.

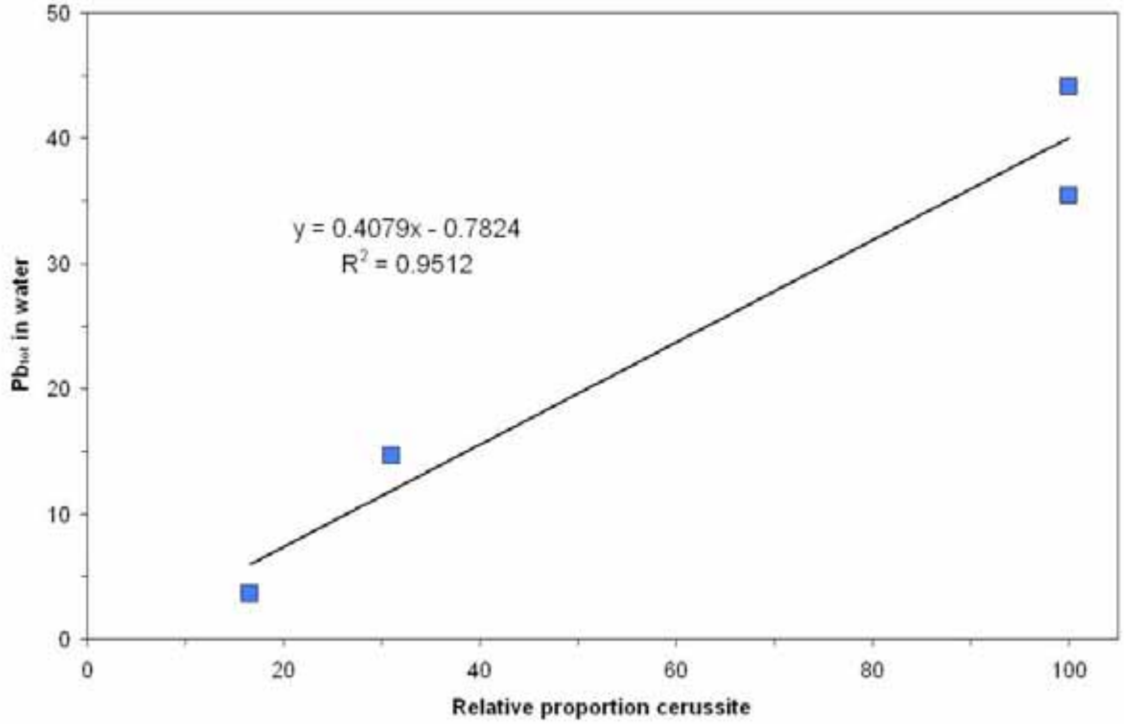


Figure F.18 Relationship of Average Total Lead Measured in Sequential Samples to the Relative Proportion of Cerussite Among the Scale Minerals (the dominant mineral is assigned a value of 100 percent and the other minerals scaled accordingly by peak intensity)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.17
Correlation Coefficients for Pb Total vs Water and Scale Parameters

Water Parameters	Correlation coefficient	Scale Parameters	Correlation coefficient
pH	-0.87	%Sn	0.73
Temperature	-0.78	%Ca	-0.96
Alkalinity	0.87	%S	0.88
Zn, ppm	0.90	%K	-0.92

Total Pb measured at the tap was most strongly related to total Zn, perhaps reflecting brass corrosion. The correlation to Cu in the water, however, was very poor, with an r squared (r^2) = -0.15. Another strong correlation between total Pb measured at the tap wais to alkalinity, but the variation in this parameter was very narrow, from 281 to 300 ppm, as was the range for temperature, from 14 to 20 °C. A better case can be made for a correlation to pH. Figure F.19 shows a strong a decrease in Total Pb with increasing pH. Note that dissolved Pb is unaffected, so the relationship is not attributable to a decrease in Pb solubility.

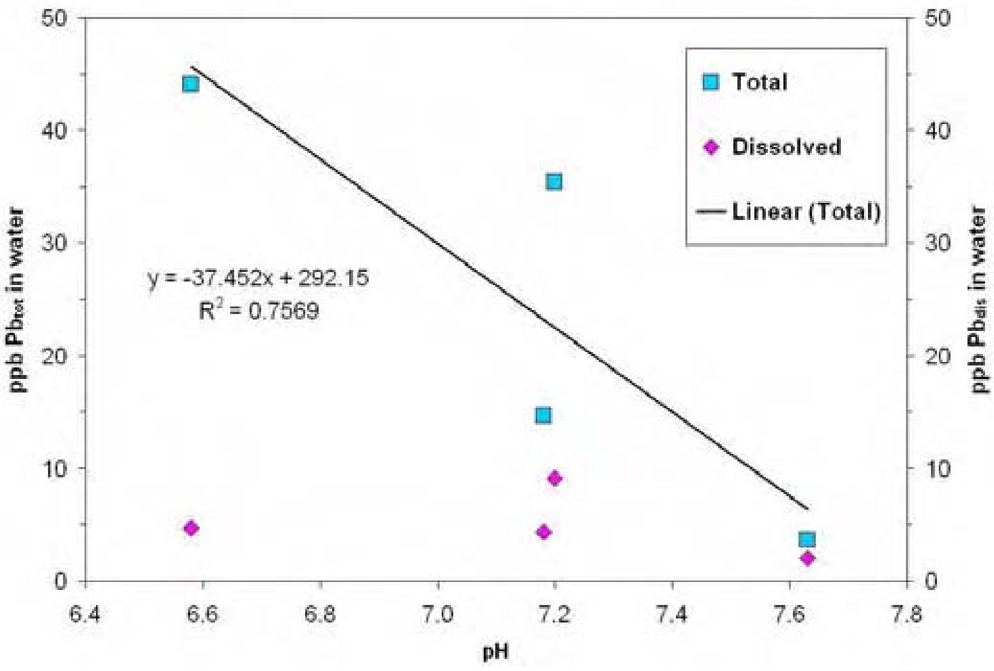


Figure F.19 Relationship of Total Pb to pH at Madison

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

For the scale chemistry, the highest r^2 values were for Ca and K. The K numbers were close to the detection limit and the range of variation was quite small, so this is a dubious correlation. For Ca, the relationship was quite robust, and explains a large part of the variation in Pb releases at these four sites (Figure F.20).

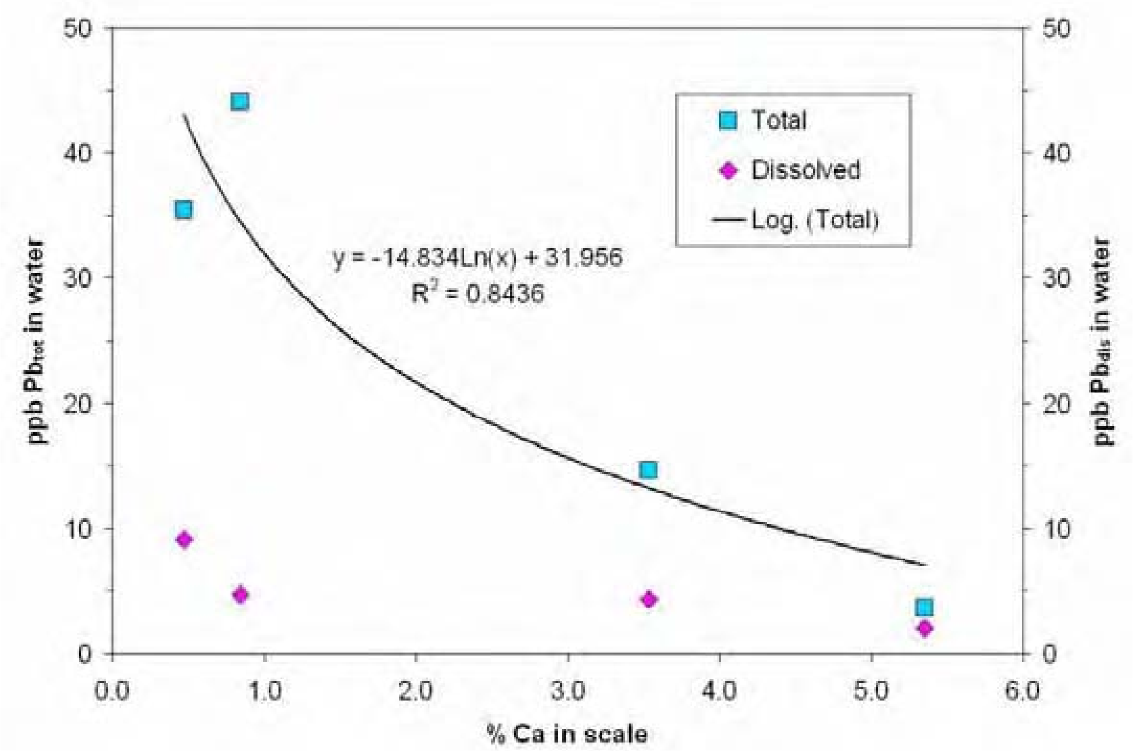


Figure F.20 Relationship of total Pb to % Ca in the scale

Other significant correlations were to S and to Sn. The presence of Sn in the Pb scales may again indicate brass corrosion in other parts of the system. The association with S raises the possibility that sulfate-reducing bacteria could be active in the scales and that some Pb release may be attributable to microbially-influenced corrosion.

A final observation that can be made is that within the solids there was a strong correlation of Mn on both the lead and the brass scales to Ba (Figure F.21). No other element was so consistently associated with Mn on both scale types. The very high Mn values and the strong association with Ba suggest that radium might also be significant in these scales, because of the close geochemical similarity of radium to barium.

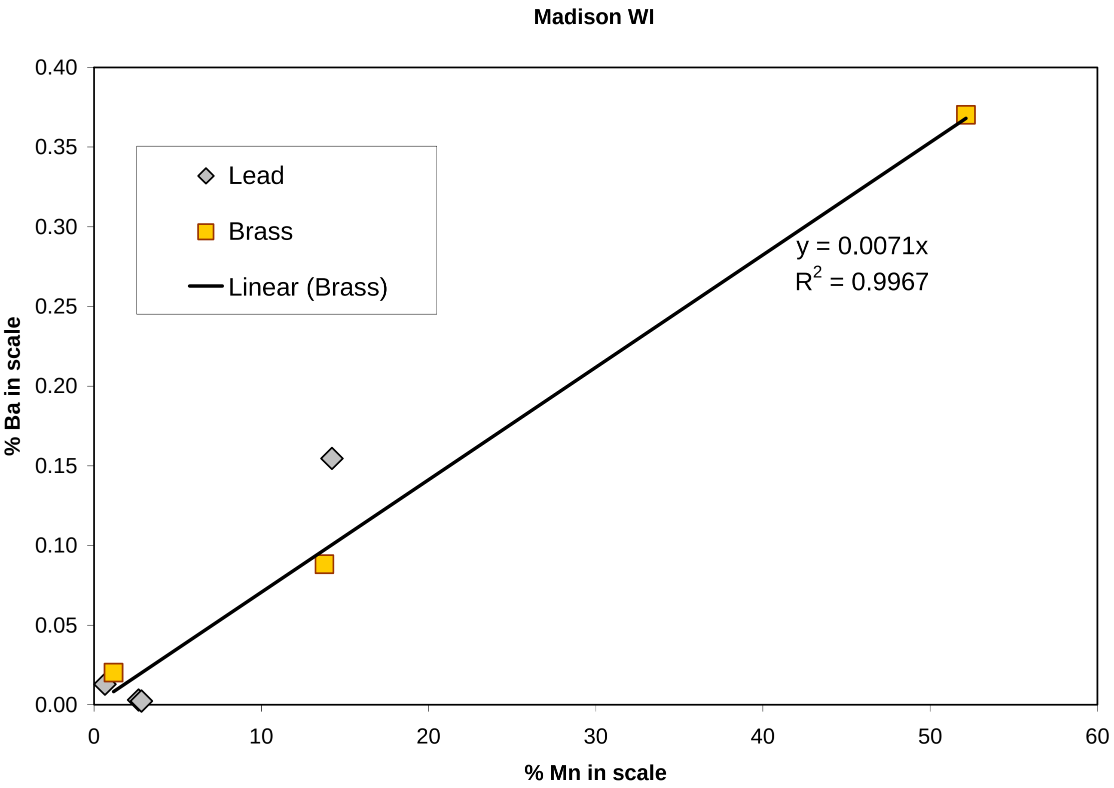


Figure F.21 Correlation of %Ba vs. % Mn in Scale for Lead and Brass Specimens from Madison

PHREEQC modeling. The solution speciation-reaction model PHREEQC (developed by the US Geological Survey, USGS) (Parkhurst et al 1980) was used to model likely scale phases for the Madison specimens. Water chemistry values were used as inputs to the model.

Site M-1. This site had the highest dissolved Pb and Zn. It is closest to saturation with respect to cerussite, but still is slightly undersaturated (Table F.18).

Table F.18
Site M-1: Saturation State of Water from PHREEQC Model

Mineral	Formula	Saturation Index
Calcite	$CaCO_3$	0.00
Cerussite	$PbCO_3$	-0.80
Malachite	$Cu_2(OH)_2CO_3$	-1.44
Manganite	MnOOH	-0.38
Pyrolusite	MnO_2	-0.43

Site M-2. Site M-2 had the lowest dissolved and particulate Pb and the lowest total Mn. It also had the highest pH and the highest supersaturation for calcite and the Mn minerals manganite and pyrolusite (Table F.19). Water at the other sites were undersaturated with respect to these minerals, despite abundant Ca and Mn in the scales. This result suggests that transient pH values exert a strong control over scale chemistry. The Pb minerals remain undersaturated at all the sites over the pH range 6.6 to 7.6. Raising the treatment pH for the system could have a beneficial effect on Mn as well as Pb releases, but would inevitably lead to more $CaCO_3$ precipitation.

Table F.19
Site M-2 Saturation State of Water from PHREEQC Model

Mineral	Formula	Saturation Index
Calcite	$CaCO_3$	0.43
Cerussite	$PbCO_3$	-1.39
Malachite	$Cu_2(OH)_2CO_3$	0.69
Manganite	$MnOOH$	0.05
Pyrolusite	MnO_2	0.72

Site M-3. This site had the highest dissolved Mn, but the water was slightly undersaturated with respect to manganese minerals because of lower pH (Table F.20). This site also had the highest level of Mn in the scale on the Pb pipes. The combination of undersaturation and high Mn in the solids suggests that the scale is likely to exhibit appreciable Mn release. This may physically destabilize the Pb scales, which may be correlated to the much higher particulate Pb here than at site M-2.

Table F.20
Site M-3 Saturation State of Water from PHREEQC Model

Mineral	Formula	Saturation Index
Calcite	$CaCO_3$	-0.07
Cerussite	$PbCO_3$	-1.11
Malachite	$Cu_2(OH)_2CO_3$	0.71
Manganite	$MnOOH$	-0.15
Pyrolusite	MnO_2	-0.42

Site M-4. Site M-4 had the highest particulate Pb and the lowest pH. The lower pH seems to act not through increasing cerussite solubility (this mineral is undersaturated everywhere), but by enhancing the dissolution of calcite and the Mn minerals, which experienced by far their greatest undersaturation at this site (Table F.21).

Table F.21
Site M-4 Saturation State of Water from PHREEQC Model

Mineral	Formula	Saturation Index
Calcite	$CaCO_3$	-0.69
Cerussite	$PbCO_3$	-1.34
Malachite	$Cu_2(OH)_2CO_3$	0.05
Manganite	MnOOH	-2.19
Pyrolusite	MnO_2	-3.55

District of Columbia Water and Sewer Authority (DCWASA)

The District of Columbia Water and Sewer Authority (DCWASA) provides drinking water to the District of Columbia and surrounding areas. Water is received from the Washington Aqueduct (WA), which is treated at two water treatment plants, the McMillian and the Dalecarlia Water Treatment Plants, and DCWASA receives finished water from both plants. These plants utilize conventional treatment with alum coagulation, filtration, and addition of fluoride, chlorine, and ammonia. Prior to November 2000, the WA used free chlorine for residual disinfection at both plants. In November, 2000, chloramine disinfection was implemented, and in August 2004, orthophosphate was added at both plants for corrosion control. Table F.22 lists typical finished water quality characteristics for finished water from the WA.

Table F.22
Typical Finished Water Quality from the Washington Aqueduct

Finished Water Quality Parameter (annual average from 2005)	Dalecarlia WTP	McMillan WTP
pH	7.7	7.7
Alkalinity, mg/L $CaCO_3$	86	74
Hardness, ppm	137	129
Conductivity, uS/cm	373	360
Disinfectant residual, ppm (Chlormamines)	3.7 – 3.8	3.7 – 3.8
Total Trihalomethanes, ppb	30.4	38.4
Haloacetic Acids – 9, ppb	32.5	29.7

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Site Information and Sample Collection

DCWASA conducted lead service line (LSL) replacements at four sites from July 2005 through November, 2006. Table F.23 lists the material, diameter, length, and volume of water contained in each section of piping from the four sites. The piping in the residences was generally ¾" copper, however there was limited use of plastic piping at Site D-3 and D-4. Existing lead service lines were 3/4' or 1" in diameters, and lengths ranged from approximately 31.5 to 42 feet from the house to the main.

At Sites D-1 and D-2, full lead service line replacements occurred, i.e. the entire lead service from the main to the house was replaced with copper. Partial lead service line replacements were completed at Sites D-3 and D-4., with the lead service line from the main to the property line replaced with copper while the lead service from the property line to the house remained in place. At Site D-3, 15.6 feet of the lead service line (from the meter to the road) was replaced with copper, leaving 16 feet of lead service in place on the customer side. At Site D-4, 37.5 feet of lead service was replaced (from the curbstop to the road), with 3 feet left in place. At all sites, test pitting was conducted, i.e. a test pit was dug to identify the service line material prior to selection of the site.

Table F.23
Site Survey Information for DCWASA

Site No.	Location	Piping	Pipe Length, feet	Volume, L
D-1 (Full Replacement)	Kitchen faucet to service line entry to house	3/4" copper	32.0	3.04
	Service	1" lead	39.0	6.00
	Total			**9.04**
D-2 (Full Replacement)	Kitchen faucet to service line entry to house	3/4" copper	42.0	3.99
	Service	1" lead	42.0	6.47
	Total			**10.46**
D-3 (Partial Replacement)	Kitchen faucet to service line entry to house	1/2" PVC 3/4" copper	0.5 52.5	0.005 4.56
	Service	3/4" lead	31.6 (16 feet replaced)	2.74 (1.39)
	Total			**7.31**
D-4 (Partial Replacement)	Kitchen faucet to service line entry to house	1/2" PVC 3/4" copper	0.5 62.3	0.005 5.41
	Service	3/4" lead	40.5 (37.5 replaced)	3.52 (3.26)
	Total			**11.47**

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Results

Water Quality. Chlorine concentration, total dissolved solids (TDS), pH, and temperature were performed on-site and alkalinity, copper, zinc, and orthophosphate levels were analyzed from selected stagnation samples collected before and after replacement at sites D1, D2, and D3. Results are displayed in Tables F.24 through F.26. Results were consistent within and between sites, with the exception of temperature and total chlorine residual which fluctuated during the course of the sampling.

Lead Levels. Total and dissolved lead levels were measured from the sequential volumes of water collected at the tap during multiple sampling events at each site. Results from the first five stagnation samples collected before LSL replacement were also combined to determine a calculated first liter lead level result for comparison with first liter lead level results after replacement.

Total and dissolved lead level results from sequential sampling are displayed in Figures F.22 through F.29. In general, samples collected before LSL replacement were below the action level of 15 ug/L, with the exception of selected volumes representative of the lead service line at sites D-1 and D-2. In the 2 days after LSLR, samples exhibited high particulate lead, but by 3 days after replacement, total lead measured from sites where full replacement took place were lower than lead measured before replacement. At sites where partial LSLR took place, lead levels were still elevated three days after replacement, and were similar or slightly lower by 1 and 2 months after replacement when compared to levels measured before. With the exception of samples collected 1, 2, and 3 days after replacement, the majority of lead measured was in dissolved form.

Lead measured in flowing samples was low (Figure F.30 through F.33) with the exception of some higher particulate lead measurements at some sites possibly due to the test pitting procedure which may have disturbed the piping.

Calculated first liter lead levels are displayed in Figures F.34 through F.37. Full LSL replacement sites (D1 and D2) were below the action level before replacement, and continued to be low 1,2, and 3 days after. At the two partial LSLR sites (D3 and D4), site D-3 exhibited higher first liter lead levels 2 months after replacement when compared to levels measured before LSLR, however in both cases, lead levels were below 10 ug/L. At site D-4, first liter lead levels were higher for the three days after LSLR when compared to first liter lead levels before the replacement. Sampling was discontinued at this site 3 days after the replacement as the homeowner had changed out the internal piping in the home because of the presence of discolored water. It is suspected that this site may have contained unidentified galvanized iron piping which may have contributed to the discolored water complaints and higher lead levels.

Table F.24
Site D-1 Water Quality

Relation to Lead Service Line Replacement	pH	Temp. (deg. C)	TDS (mg/L)	Free Chlorine (mg/L)	Total Chlorine (mg/L)	Alkalinity mg/L as $CaCO_3$	Copper (mg/L)	Zinc (mg/L)	Orthophosphate (mg/L as PO_4)
Before	7.46	24.4	204	0.09	2.2	87	0.03	111.5	2.98
1 Day After	7.43	27	204	0.05	2.0	-	-	-	-
2 Days After	7.55	26.5	210	0.07	2.1	-	-	-	-
3 Days After	7.56	27.1	188.8	0.03	1.8	140	0.06	158.9	2.82
1 Month After	7.4	24.2	217	0.06	2.3	90	0.07	163.6	3.32
2 Month After	7.66	21.6	211	0.05	2.6	82	0.08	149.9	3.44

Table F.25
Site D-2 Water Quality

Relation to Lead Service Line Replacement	pH	Temp. (deg. C)	TDS (mg/L)	Free Chlorine (mg/L)	Total Chlorine (mg/L)	Alkalinity mg/L as $CaCO_3$	Copper (mg/L)	Zinc (mg/L)	Orthophosphate (mg/L as PO_4)
Before	7.52	24.9	206	0.05	2.0	82	0.06	16.52	3.08
1 Day After	7.38	25.7	205	0.05	1.9	-	-	-	-
2 Days After	7.45	25.2	213	0.07	2.3	-	-	-	-
3 Days After	7.66	25.5	204	0.04	1.7	90	0.12	24.31	3.08
1 Month After	7.56	23.5	218	0.05	2.4	87	0.09	21.12	3.4
2 Month After	7.58	20.2	212	0.04	2.7	83	0.17	23.51	3.32

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.26
Site D-3 Water Quality

Relation to Lead Service Line Replacement	**pH**	**Temp. (deg. C)**	**TDS (mg/L)**	**Free Chlorine (mg/L)**	**Total Chlorine (mg/L)**	**Alkalinity mg/L as $CaCO_3$**	**Copper (mg/L)**	**Zinc (mg/L)**	**Orthophosphate (mg/L as PO_4)**
Before	7.83	23.7	465.1	0.05	2.6	-	-	-	2.34
1 Day After	7.47	23.4	355	0.07	1.6	-	-	-	
2 Days After	7.47	23.8		0.04	2.2	-	-	-	
3 Days After	7.42	23.3	381	-	2.3	85	-	-	2.26
1 Month After	7.45	25.9	421	0.05	1.8	90	-	-	2.12
2 Month After	7.41	23.8	366	0.04	1.9	-	-	-	3.56

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

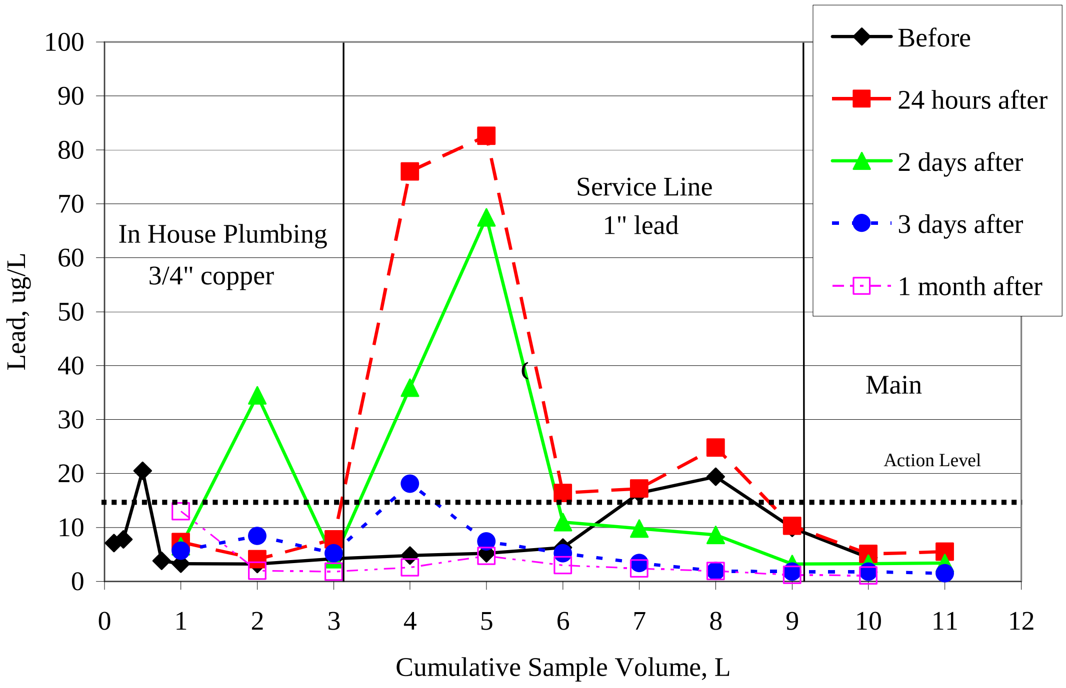


Figure F.22 Site D-1 Total Lead Concentration Profiles (stagnation)

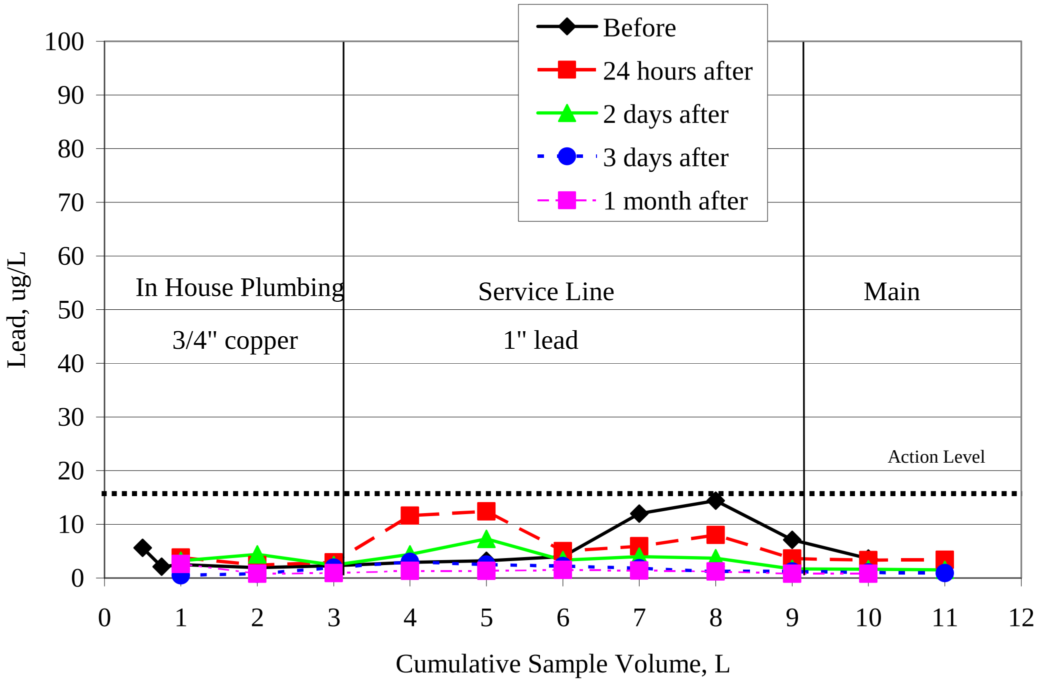


Figure F.23 Site D-1 Dissolved Lead Concentration Profile (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

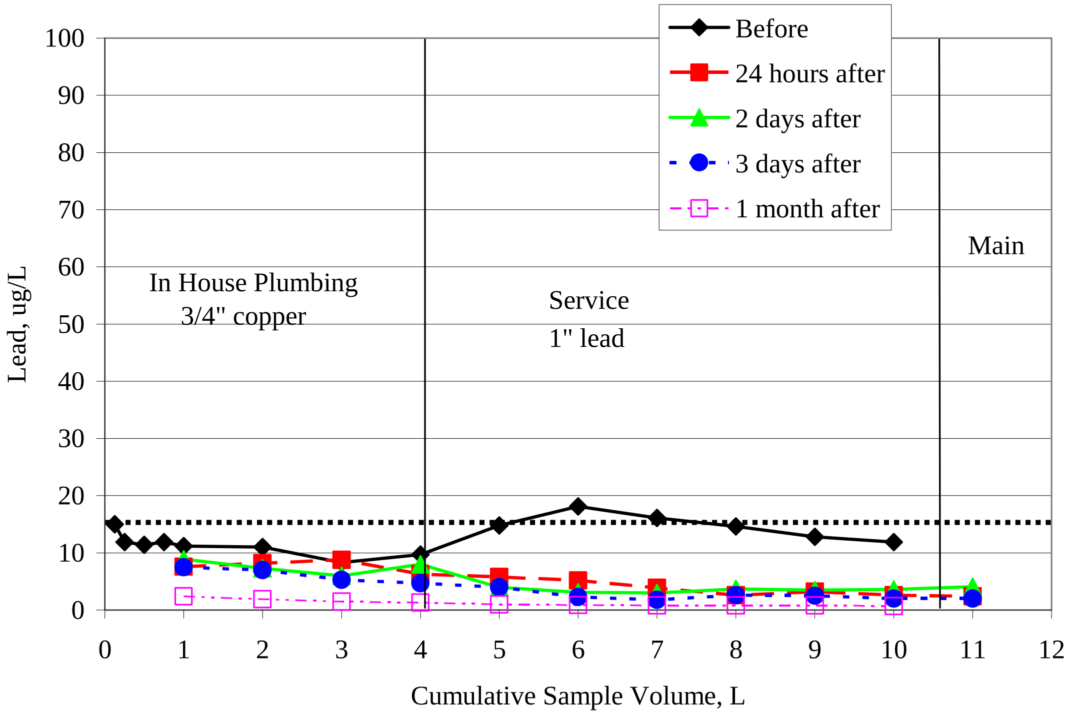


Figure F.24 Site D-2 Total Lead Concentration Profile (stagnation)

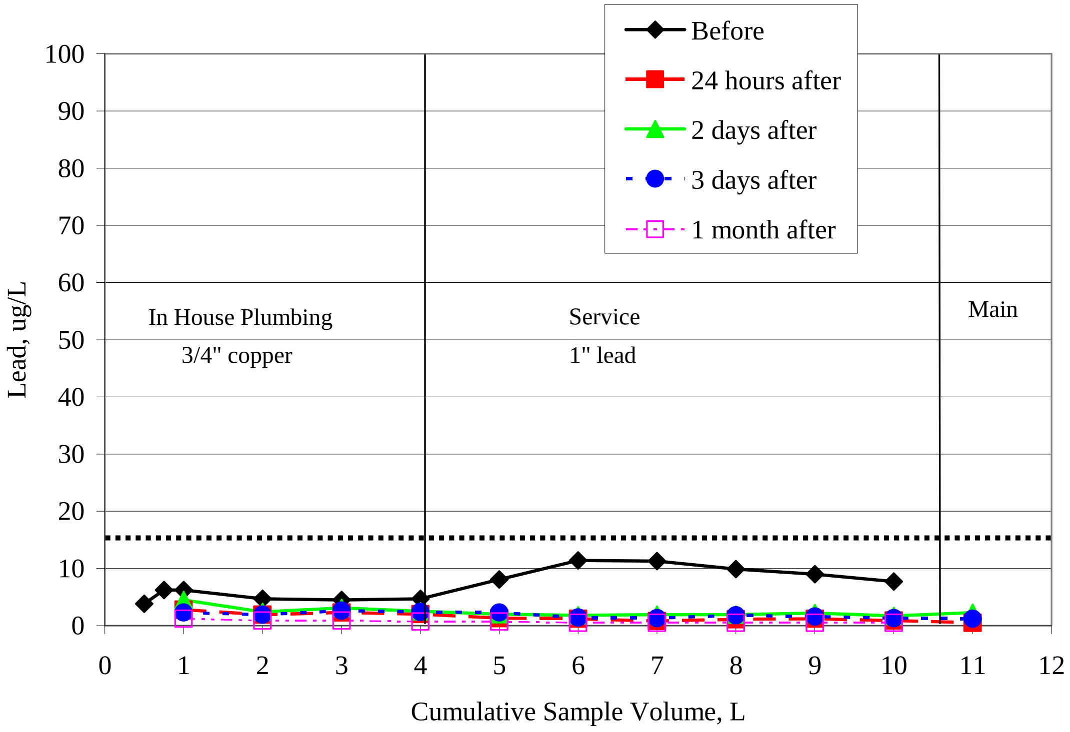


Figure F.25 Site D-2 Dissolved Lead Concentration Profile (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

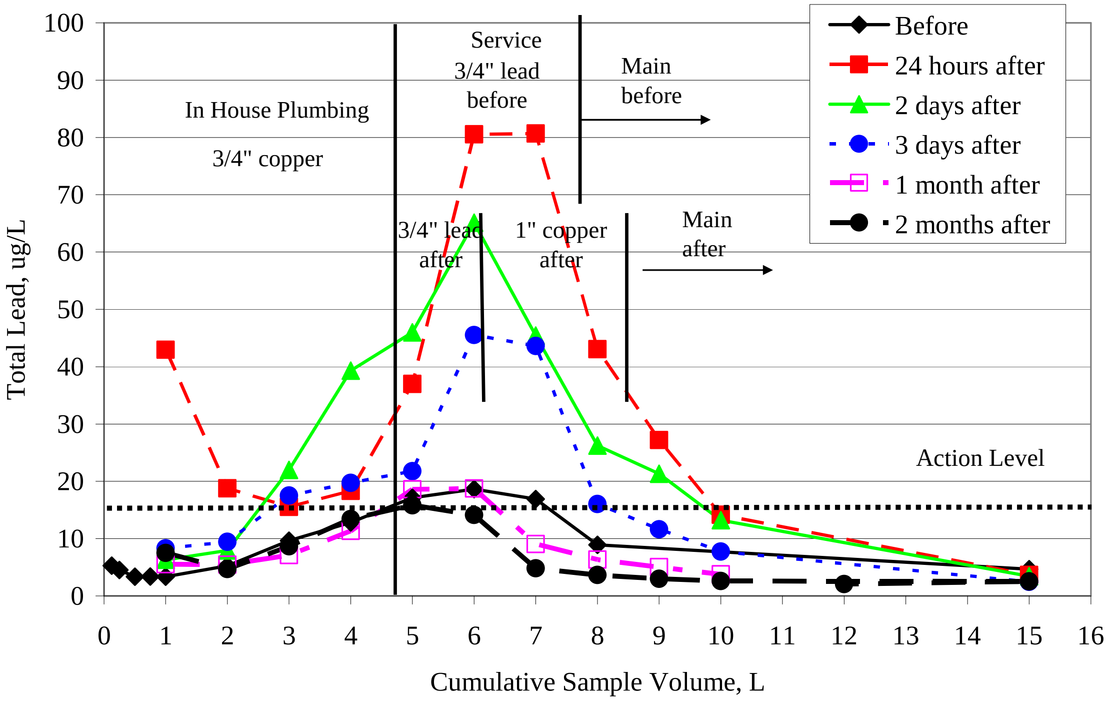


Figure F.26 Site D-3 Total Lead Concentration Profile (stagnation)

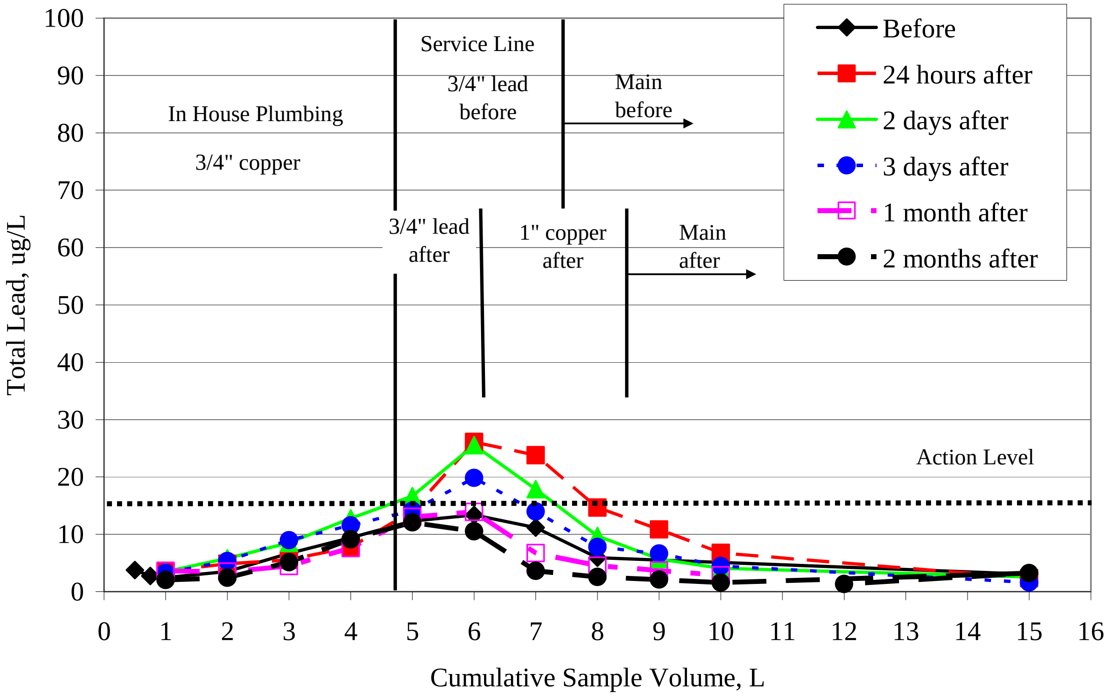


Figure F.27 Site D-3 Dissolved Lead Concentration Profile (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

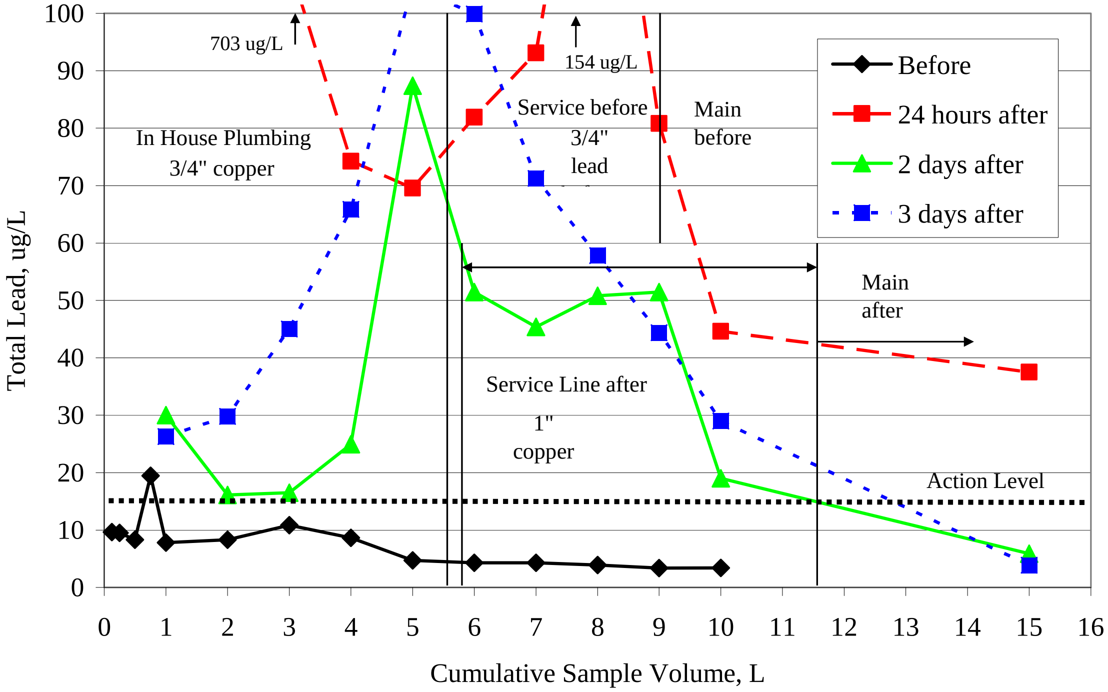


Figure F.28 Site D-4 Total Lead Concentration Profile (stagnation)

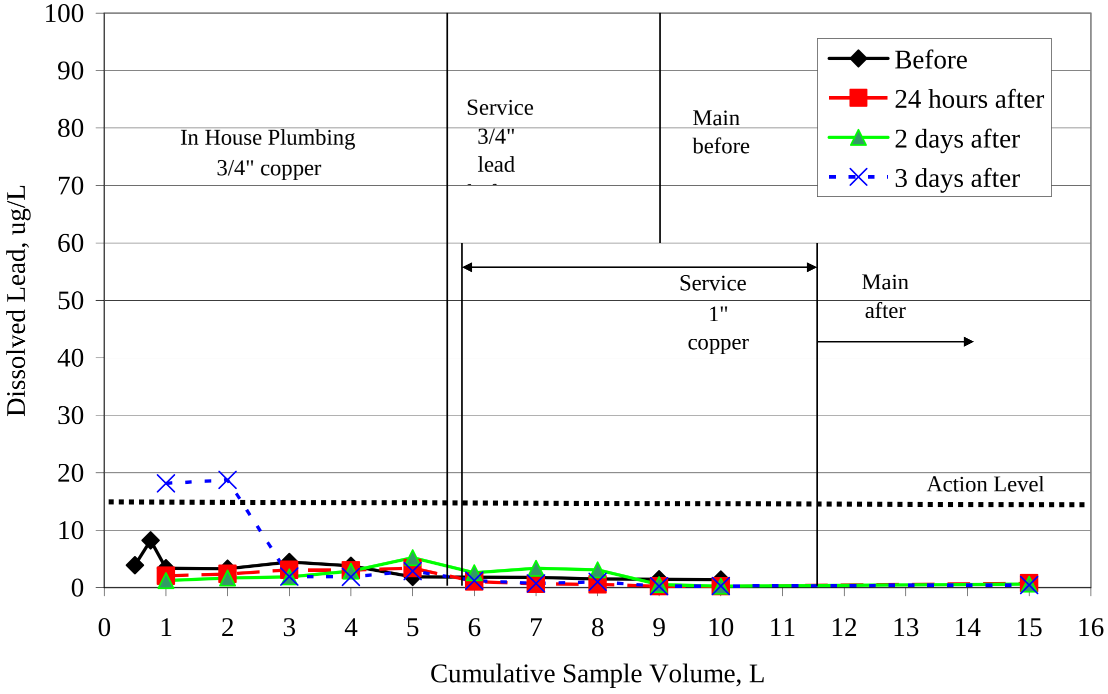


Figure F.29 Site D-4 Dissolved Lead Concentration Profile (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

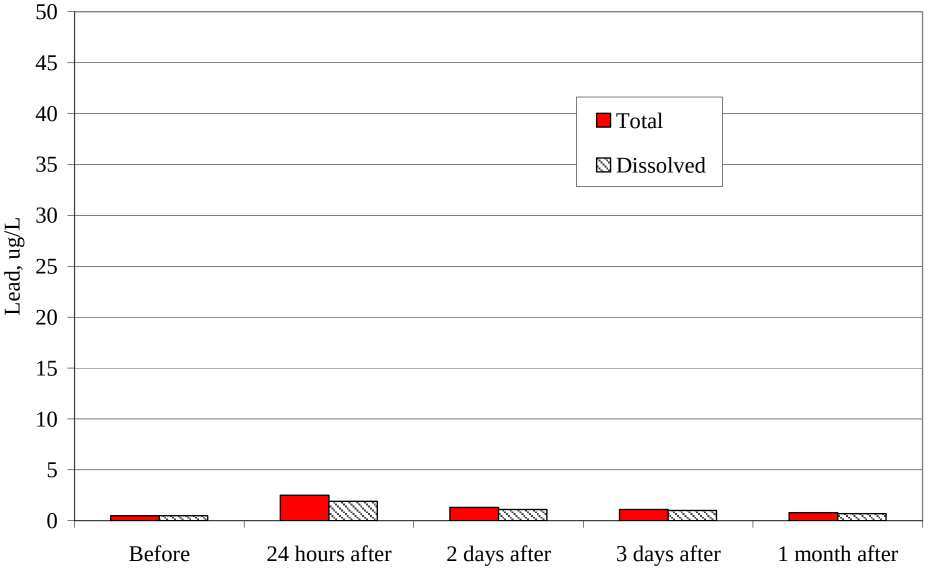


Figure F.30 Site D-1 Total and Dissolved Lead from Flushed Samples

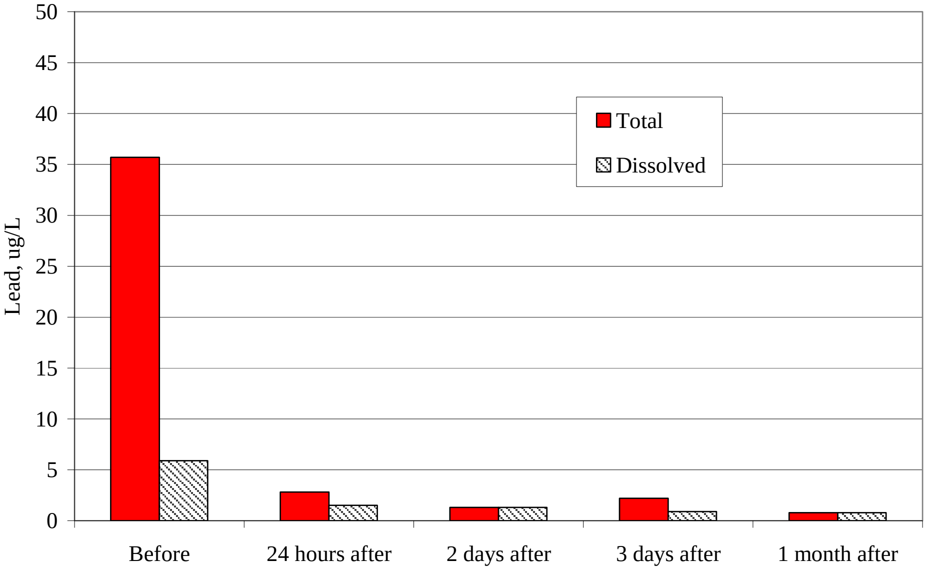


Figure F.31 Site D-2 Total and Dissolved Lead Levels from Flushed Samples

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

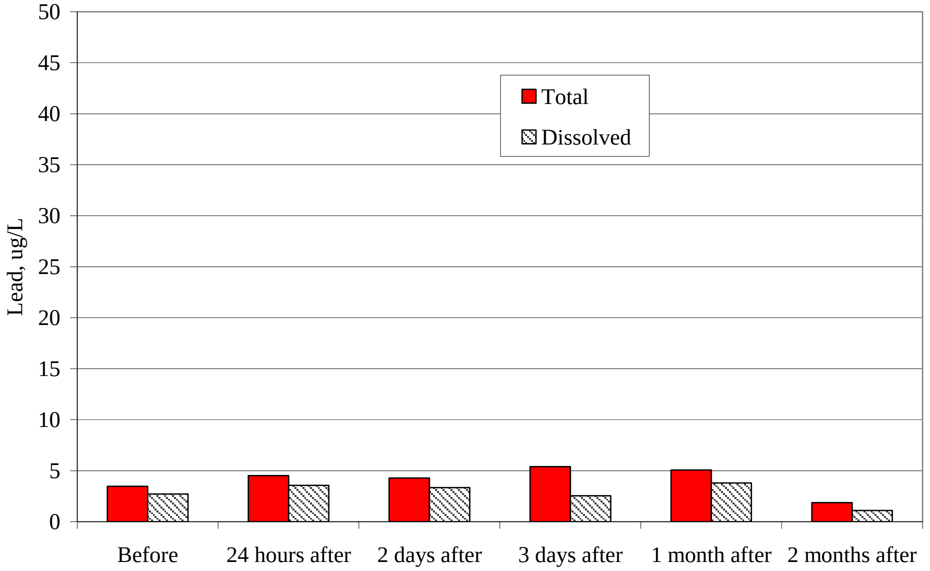


Figure F.32 Site D-3 Total and Dissolved Lead Levels from Flushed Samples

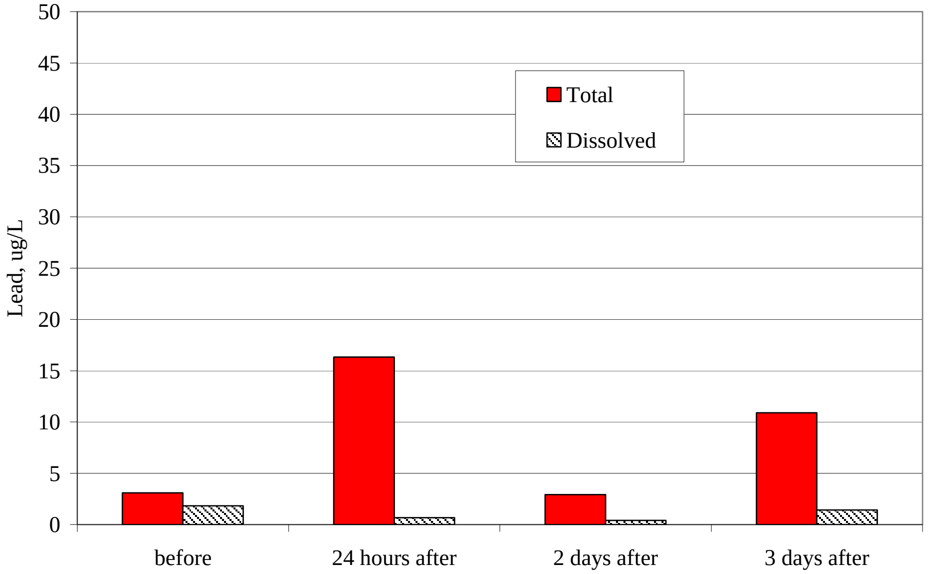


Figure F.33 Site D-4 Total and Dissolved Lead Levels from Flushed Samples

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

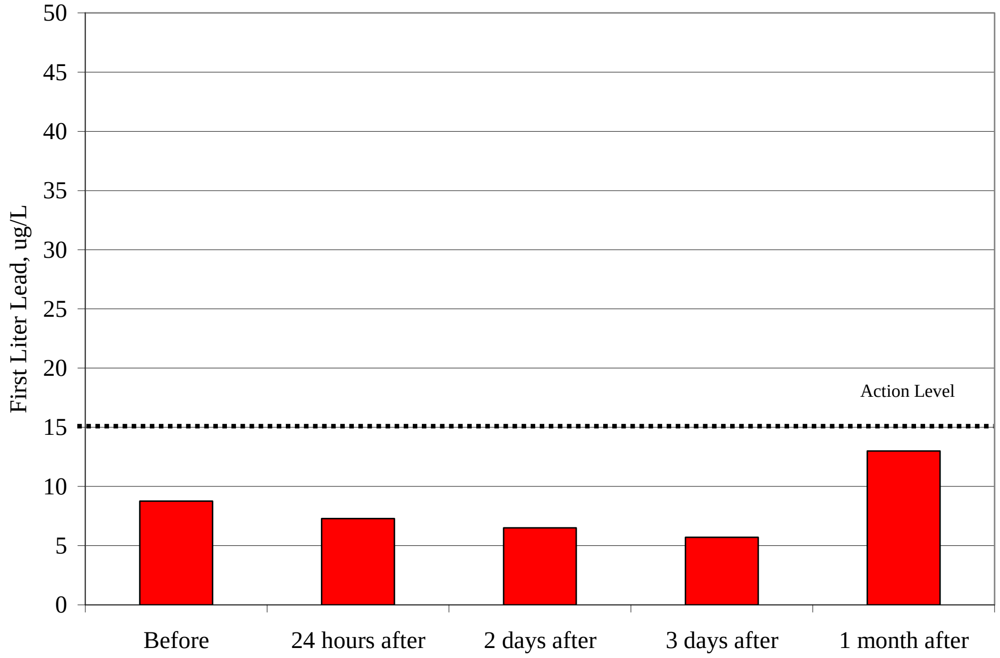


Figure F.34 Site D- 1 Calculated First Liter Lead Levels (stagnation)

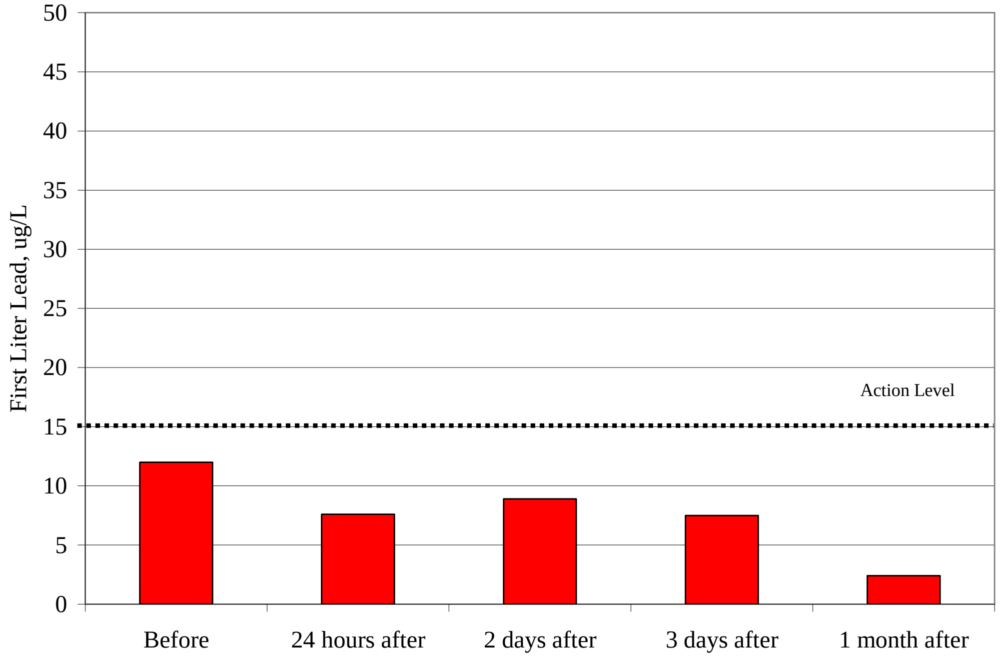


Figure F.35 Site D-2 Calculated First Liter Lead Levels (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

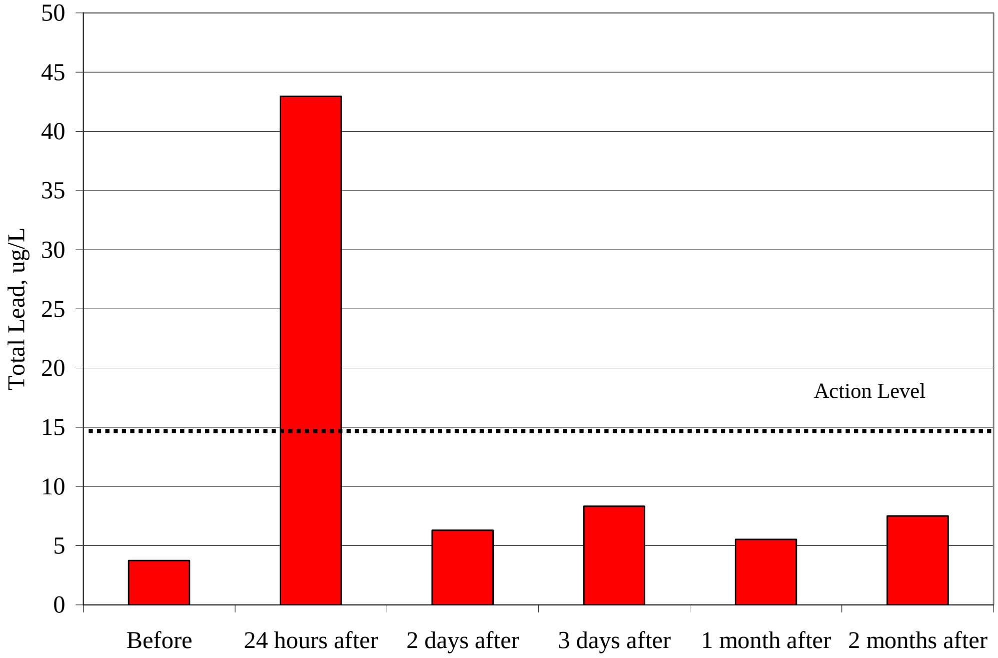


Figure F.36 Site D-3 Calculated First Liter Lead Levels (stagnation)

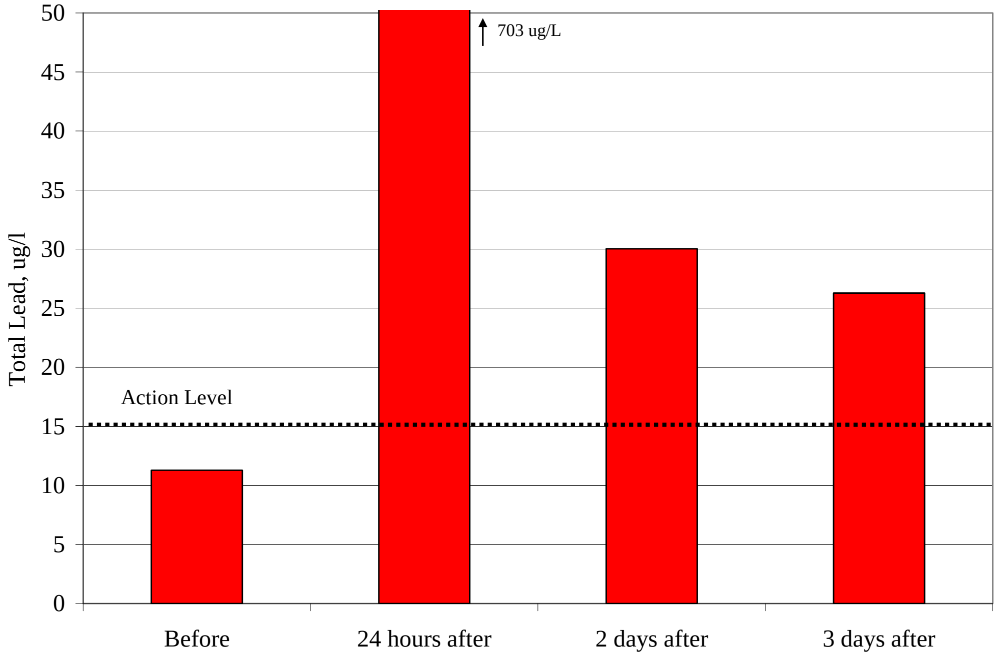


Figure F.37 Site D-4 Calculated First Liter Lead Levels (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scale Analysis. Pipe samples, which included lead service lines and attached brass fittings, were received by the University of Cincinnati from two of the lead service replacement sites. Eight sections of pipe were examined for scale properties and the laboratory numbers assigned to each section of these pipes is shown in the table below (Table F.27). Scales scraped from these pipes were analyzed by x-ray diffraction, x-ray fluorescence, Raman spectroscopy, and SEM-EDS for mineralogy and chemistry. These results were then compared to water chemistry.

Table F.27
Samples Received from DCWASA for Scale Analyses

Site	Lab number*	Material
D-1	01_PX03	Lead pipe with gooseneck connection to brass
D-1	01_PP04	Lead pipe
D-2	01_PP05	Lead pipe
D-2	01_PP06	Lead pipe
D-2	01_PP07	Lead pipe
D-2	01_PP08	Lead pipe
D-2	01_PX09	Lead pipe connected to brass
D-2	01_PC10	Copper pipe

* definitions for the nomenclature for the laboratory I.D. numbers can be found in Appendix G

Water chemistry. System-wide. As mentioned previously, DCWASA receives water from the Washington Aqueduct from two treatment plants, Dalecarlia serving predominantly the NW quadrant of the city, and McMillan, serving the rest of the city. Water quality parameters for the two systems are slightly different (Table F.28). Note in particular the higher Mn and V in the water from the Dalecarlia plant as compared to McMillan.

Table F.28
Summary of Water Quality Data from Washington Aqueduct for 2006*

Parameter			**mg/l**								**µg/l**			
Treatment plant	pH	T, °C	Alkalinity as $CaCO_3$	Cl	PO_4	SO_4	Ca	K	Mg	Na	Al	Ba	Mn	V
Dalecarlia	7.7	18.3	83	28	2.46	48	42	2.8	8	12.6	42	36	3.7	0.6
McMillan	7.7	16.7	70	28	2.47	50	49	2.9	8	15.0	49	35	1.3	b.d.

*source: DC WASA Annual Water Quality Report
b.d. = Below detection
As, Fe, Se, U were below detection

Water chemistry. Site-Specific. Some water quality parameters were also available for the specific sites where LSL replacement took place (Table F.29). Note once again the lower Mn in the McMillan part of the system. Iron (Fe), which was below detection in the water leaving the plant, was appreciable at all sites except site D3. Aluminum($Al(OH)_3$) precipitation may also be possible.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.29
Water Quality Parameters at LSL Sites Before Replacement

Parameter	**units**	**Site D-1 NW**	**Site D-2 NW**	**Site D-3 NE**	**Site D-4 NW**
		Dalecarlia	Dalecarlia	McMillan	Dalecarlia
pH		7.46	7.52	7.58	-
Temp.	oC	24.4	24.9	25.9	-
Free Chlorine	mg/l	0.09	0.05		-
Total Chlorine	mg/l	2.2	2	3.7	-
Alkalinity	mg/l as CaCO3	87	82	-	-
Chloride	mg/l	-	-	24.6	-
Fluoride	mg/l	-	-	1.02	-
Nitrate	mg/l as N	-	-	1.69	-
Nitrite	mg/l as N	-	-	0	-
Orthophosphate	mg/l as PO_4	-	-	2.20	-
Sulfate	mg/l	-	-	46	-
Aluminum	µg/l	35.7	53.6	37.8	33.0
Arsenic	µg/l	0.52	0.49	0.24	0.32
Barium	µg/l	40.1	42	37	33
Copper	µg/l	46.9	38.1	14.2	7.5
Iron	µg/l	35.8	68.5	0	4.0
Lead	µg/l	5.7	11.9	3.5	3.1
Manganese	µg/l	3.06	3.72	1.67	3.66
Molybdenum	µg/l	1.91	1.85	0.87	0.86
Nickel	µg/l	1.42	1.99	0.61	0.99
Selenium	µg/l	0.67	0.64	0.45	0.49
Strontium	µg/l	222	233	163	164
Vanadium	µg/l	0.93	0.88	0.75	0.64
Zinc	µg/l	111	16.5	7.5	2.2

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scale Properties. Pipe samples were received from sites D1 and D2, which are on the same street in NW Washington. Comparative data was available from pipes extracted for the DC-Aqueduct pipe loop studies (Table F.30), but unfortunately it was not known from what parts of the city the Aqueduct samples were extracted.

Scale chemistry was quite similar at the two sites tested, and was comparable to the system-wide values. Of particular note was that the surface layer of the pipes in all cases was rich in Fe, Mn, and V. The Mn/Fe ratio was almost always greater than 1.0. Vanadium (V) was found in these scales, reaching 5600 mg/kg. Such values are higher than seen in other utilities, but were also found in the DC pipes extracted for the pipe loop studies. The source of this V is unknown, but it looks unlikely to be the source water, where V values are close to or below detection.

Site D1. Visually, the scale from the lead pipe at site D1 was a mixture of several Pb minerals (Figure F.38). The white mineral is the lead phosphate pyromorphite; the dark brown is the lead oxide plattnerite mixed with manganese oxide (amorphous). Based on x-ray diffraction, the scale mineralogy is dominated by plattnerite with lesser amounts of pyromorphite, cerussite, and litharge (Figure F.39). In SEM imaging, Ca-Pb phosphates were also seen (Figure F.40). These are Pb-substituted apatites.

Site D2. This pipe had a smooth, even surface scale dominated by plattnerite and amorphous Mn oxide. The white pyromorphite patches seen at site D1 were absent in this specimen (Figure F.41). SEM-EDS analysis of the scales from site D2 showed the presence of Pb-V phosphates (Figure F.42). This sample was high in vanadium, and the lead vanadate, vanadinite was identified by SEM_EDS and by Raman spectroscopy.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.30
Bulk chemical composition of scales from DC WASA supply line replacement sites (values in weight %)

Sample	Site	material	Pb	Zn	Cu	Al	Ba	Ca	Fe	Mn	P	S	Si	V
01PXB03A1	D1	Brass	0.51	0.11	69.6	0.13	0.08	0.03	b.d.	0.08	b.d.	0.50	0.00	0.00
01PP04A1L1	D1	Lead	57.4	0.02	0.61	0.62	0.02	2.22	0.28	1.29	0.96	0.14	0.26	0.15
01PP04A1L2	D1	Lead	48.6	0.01	0.23	0.60	0.01	2.78	0.09	0.25	1.07	0.19	0.15	0.05
01PP06A1L1	D2	Lead	56.7	0.02	0.65	0.48	0.00	2.88	0.22	0.83	1.41	0.15	0.22	0.24
01PP06A1L2	D2	Lead	47.9	0.00	0.10	0.22	0.01	1.99	0.06	0.09	0.86	0.18	0.08	0.02
01PP08A1L1	D2	Lead	43.7	0.05	2.40	4.31	0.06	3.71	2.14	2.92	1.30	0.88	4.38	0.56
01PP08A1L2	D2	Lead	62.3	0.06	0.60	0.89	0.06	2.36	0.26	0.42	1.20	0.27	0.58	0.18
01PC10L1L2	D2	Copper	1.66	1.13	42.2	7.79	0.54	11.5	3.79	4.09	1.32	0.29	5.82	0.01
*System average lead pipes L1			40.4	0.19	0.43	1.06	0.06	10.1	0.68	0.75	2.35	0.71	2.55	0.14
*System average lead pipes L2			46.2	0.06	0.15	0.49	0.03	6.99	0.17	0.16	1.34	0.50	0.85	0.05

**System averages based on 18 pipe segments used in DC Aqueduct pipe loop study*

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Figure F.38 Photograph of the Surface of Scale from Pipe PP03 (Site D1)

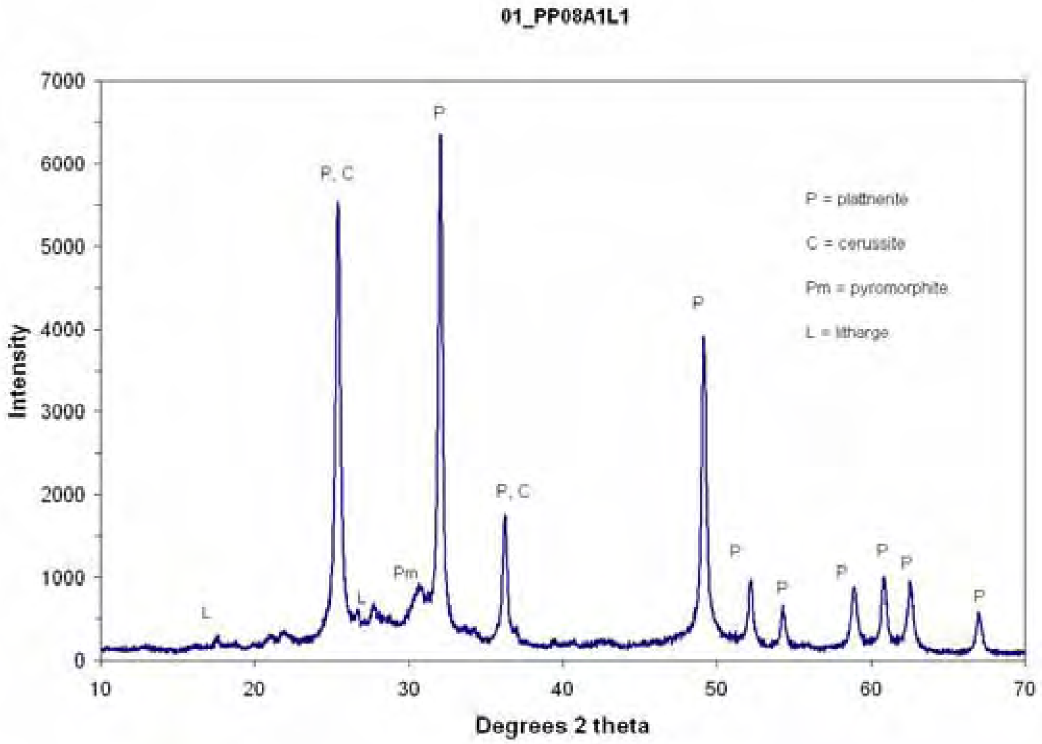
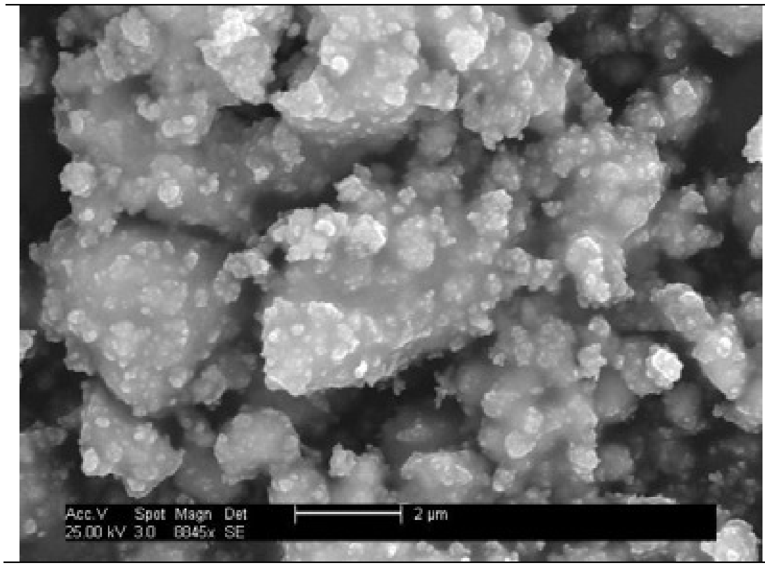


Figure F.39 Typical X-ray Diffraction Pattern for Site D1 Scales

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.



Element	*Wt%*	*At%*
C	24.7	72.7
O	5.4	12.0
P	2.1	2.5
Ca	1.6	1.4
Pb	66.0	11.2

Figure F.40 SEM Image of Ca-Pb Phosphate from D1 Scales

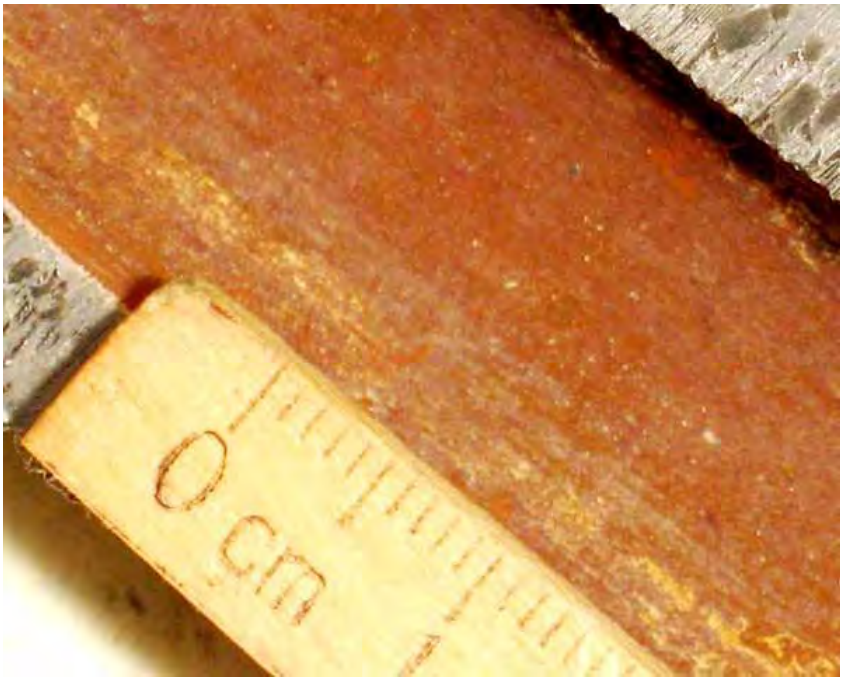
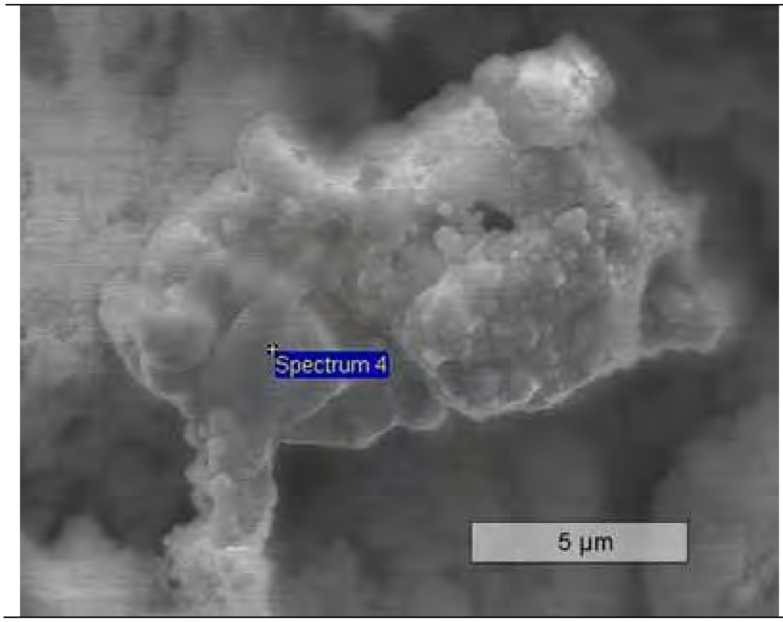


Figure F.41 Photograph of Pipe PP06 from Site D2

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.



Element	Weight%
O	12.58
P	4.93
Ca	0.28
V	12.43
Mn	0.55
Fe	0.63
Pb	68.60

Figure F.42 SEM Analysis of Sample PP06 from Site D-2

There is an isostructural series of phosphate-vanadate minerals comprising apatite, pyromorphite, and vanadinite, as follows:

apatite	$Ca_5(PO_4)_3X$	
pyromorphite	$Pb_5(PO_4)_3X$	X = F, Cl, or OH
vanadinite	$Pb_5(VO_4)_3X$	

In sample PP06, the V/P ratio ranges from 1.2 to 2.5, showing dominance of vanadinite over pyromorphite. Raman spectra and XRD tracings show the presence of a distinct vanadinite peak, which tends to be stronger than the pyromorphite peak (Figures F.43 and F.44). Some samples (e.g. PP05 – Figure F.45) showed dominance of a Pb apatite phase.

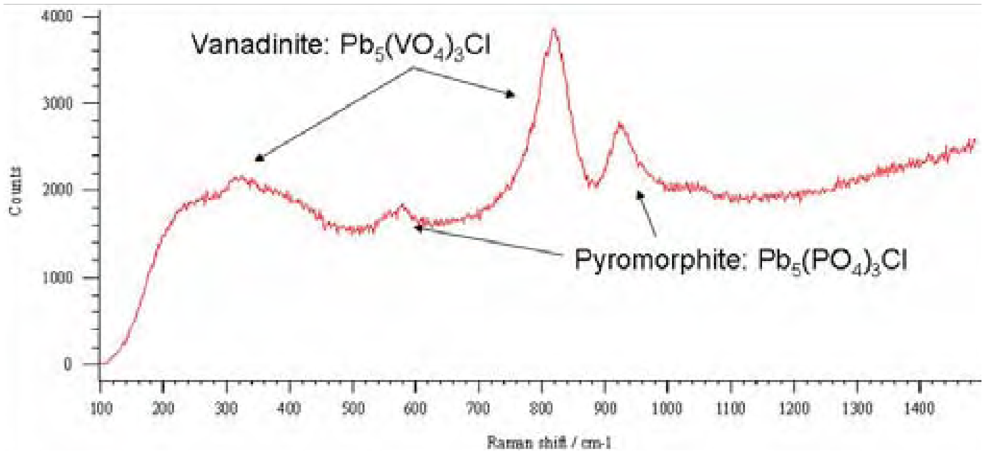


Figure F.43 Raman Spectrum of Sample 01_PP07 from Site D-2 (20x magnification, 100 percent laser power, 10 second integration time).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

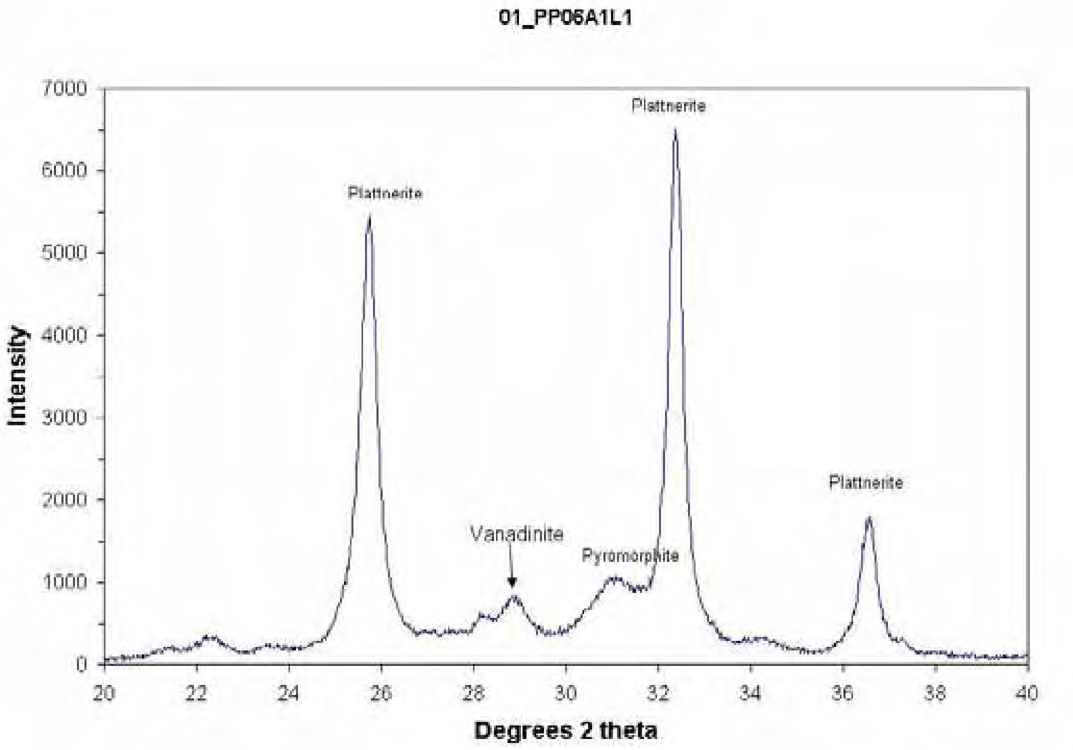
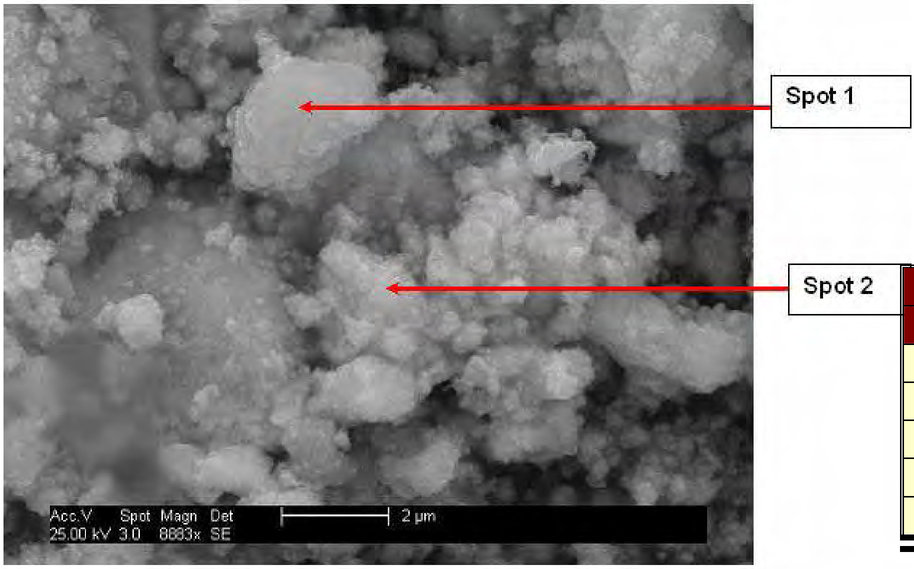


Figure F.44 Enlarged XRD Tracing of Sample PP06 from Site D-2 which shows a broad peak in the region corresponding to vanadite. Well-crystallized vanadite should have three distinct peaks at this position, so this must be nearly amorphous.



Spot 2		
Element	***Wt%***	***At%***
C	28.2	73.7
O	8.0	15.7
Al	0.3	0.4
Fe	0.9	0.5
Pb	62.4	9.4

Figure F.45 SEM Analysis of Sample PP05 from Site D-2. The image shows a hexagonal plate of Ca-Pb phosphate (spot 1) and finer-grained more equant grains of Pb carbonate (spot 2).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Figure F.46 shows the section of pipe from Site D-2 that contains the junction of the lead pipe and a brass fitting. Such junctions are generally the sites of much thicker scale development, usually consisting of greenish Cu sulfates such as brochantite [$Cu_4(SO_4)(OH)_6$] and langite-wroewolfeite [$Cu_4(SO_4)(OH)_6.2H_2O$]. The brown surface material is amorphous Mn oxide. The x-ray diffraction pattern shown in Figure F.47 displays abundant Cu sulfates with lesser amounts of Cu carbonate. Figure F.48 is the SEM image which provides the typical appearance of brochantite ($Cu_4(SO_4)(OH)_6$) at the lead-brass junction.

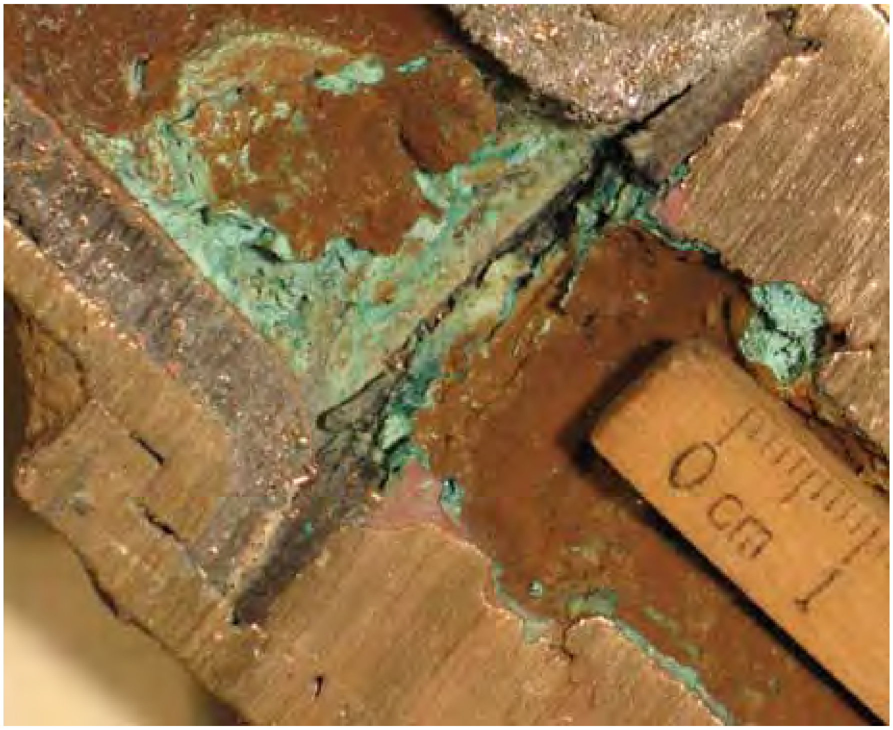


Figure F.46 Photograph of Pipe PX09 from Site D-2

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

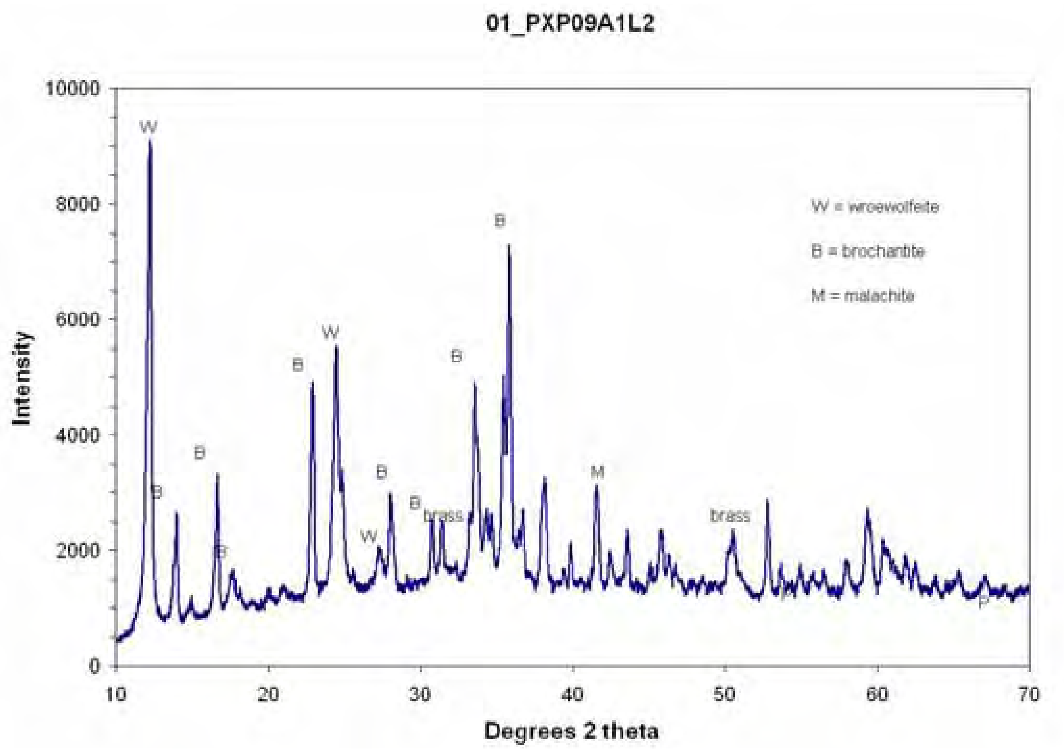


Figure F.47 X-ray Diffraction Pattern from Pipe PX09 from Site D-2

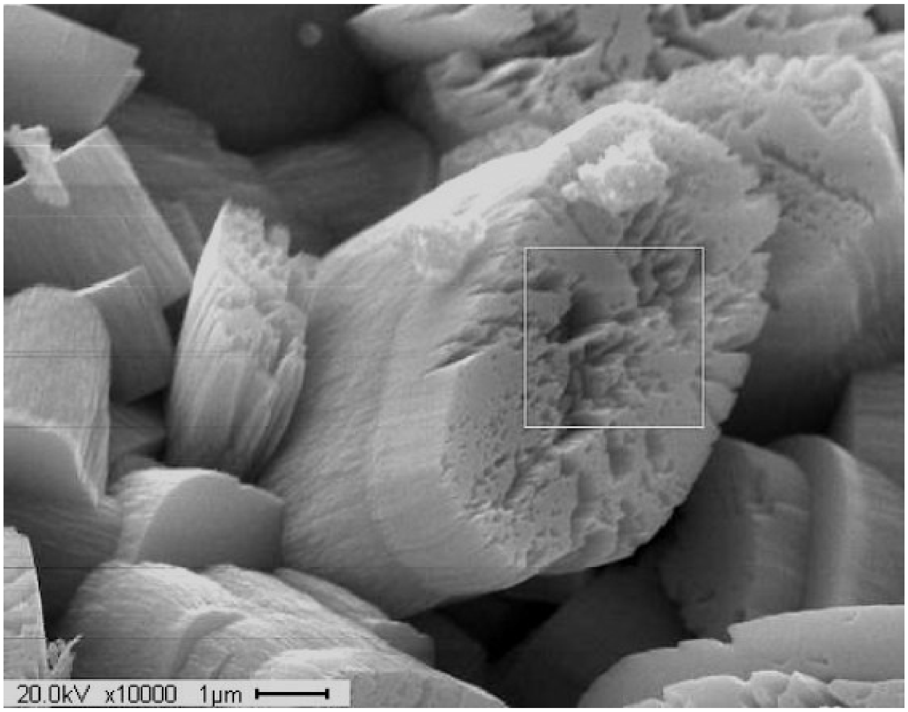


Figure F.48 SEM Image from Pipe PX09 from Site D-2 which displays the typical appearance of brochantite ($Cu_4(SO_4)(OH)_6$) at the lead-brass junction

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

PHREEQC Modeling. A speciation-saturation state model was constructed for the water compositions measured at each site, supplemented with data from the treatment plants (Table F.31). The Pb and Ca phosphates are strongly supersaturated, reflecting the addition of orthophosphate for corrosion control. It is likely that the corresponding Pb vanadate (vanadinite) is also supersaturated and furthermore that mixed phases of these three end-member minerals are likely to form. Al, Fe, and Mn oxides are supersaturated at all sites (note that for D3 no Fe was detected before replacement, but was found in other sampling rounds). Barite and calcite are at saturation, within the uncertainty of the thermodynamic data, and could well precipitate. The Cu minerals tenorite and malachite are likewise at saturation, consistent with their occurrence on brass components in the system. Lead minerals other than the phosphates are undersaturated, and can be expected to convert over time into the phosphates.

Table F.31
Saturation index of water at LSL replacement sites with respect to likely scale minerals (SI =log IAP/Kt)

Phase	Formula	D1	D2	D3	D4
Supersaturated					
Pyromorphite-Cl	Pb5(PO4)3Cl	8.82	10.42	7.65	7.50
Hydroxylapatite	Ca5(PO4)3OH	6.37	6.66	7.10	6.66
Goethite	FeOOH	5.21	5.55	n.a.	4.32
Manganite	MnOOH	2.97	3.12	2.80	3.12
Gibbsite	Al(OH)3	1.04	1.14	0.88	0.92
Saturated					
Barite	BaSO4	-0.18	-0.17	-0.27	-0.31
Calcite	CaCO3	-0.35	-0.28	-0.18	-0.29
Tenorite	CuO	-0.05	-0.06	-0.36	-0.77
Malachite	Cu2(OH)2CO3	-0.04	-0.18	-0.99	-1.59
Undersaturated					
Cerussite	PbCO3	-1.10	-0.77	-1.31	-1.35
Plattnerite	PbO2	-1.70	-1.30	-1.73	-1.88
Pyromorphite-OH	Pb5(PO4)3OH	-2.22	-0.57	-3.22	-3.48
Hydrocerussite	Pb3(OH)2(CO3)2	-3.34	-2.28	-3.76	-4.03
Brochantite	Cu4(OH)6SO4	-3.25	-3.43	-4.82	-6.25
Litharge	PbO	-6.35	-5.94	-6.34	-6.53

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Toronto

Toronto Water provides drinking water to the City of Toronto, Ontario and surrounding areas. Water from Lake Ontario is treated at four water treatment plants, the largest being the R.C Harris Water Treatment Plant. These plants utilize conventional treatment with addition of fluoride, chlorine, and ammonia. Table F.32 lists typical finished water quality characteristics for Toronto Water.

Table F.32
Finished Water Quality for Toronto Water

Finished Water Quality Parameter (annual average from 2004)	Value
pH	7.5 pH Units
Alkalinity	82.1 mg/L $CaCO_3$
Hardness	122 mg/L $CaCO_3$
Conductivity	304 μmhos/cm
Disinfectant residual	Chloramines: 1.06 ppm
Total Trihalomethanes	14.3 ppb
Haloacetic Acids – 9	7.68 ppb

Site Information and Sample Collection

Toronto Water conducted lead service line (LSL) replacements at four sites from May through August, 2006 for evaluation of full and partial lead service line replacement on lead levels at the tap. Table F.33 lists the material, diameter, length, and volume of water contained in each section of piping from the thirteen.

The piping in the residences was generally 1/2” and 3/4” copper, however there was limited use of galvanized piping and one site with a small length of PVC piping. Existing lead service lines were generally 1/2” or 5/8” in diameter, and lengths ranged from approximately 9 to 25 feet from the house to the main. At Sites T-1 and T-2, full lead service line replacements occurred, i.e. the entire lead service from the main to the house was replaced with copper. A partial lead service line replacement was planned at Site T-3, however upon excavation, it was discovered that the service line from the property line to the house was copper, therefore the remaining lead service from the property line to the main was replaced making this a full lead service replacement site. At Site T-4, a partial lead service line replacement took place, with the lead service line from the main to the property line replaced with copper (49 feet or 15 meters) while the lead service from the property line to the house (13 feet or 4 meters) remained in place. At these four sites (T1, T2, T3, and T4), water samples were collected prior to LSL replacement at the kitchen faucet using the cold water portion of the faucet, for three consecutive days after replacement, and at 1 and 2 months after replacement.

Table F.33
Site Survey Information for Toronto Water

Site No.	Location	Piping	Pipe Length, feet (meters)	Volume, L
T-1 (Full Replacement)	Kitchen faucet to service line entry to house	1/2" copper 1/2" pvc 3/4" copper	6.5 (2.0) 27.9 (8.5) 8.5 (2.6)	0.30 1.05 0.81
	Service	1/2" lead 5/8" lead	19.7 (6.0) 36.1 (11.0)	0.76 3.14
	Total			**6.06**
T-2 (Full Replacement)	Kitchen faucet to service line entry to house	1/2" copper 3/4" copper	13.8 (4.2) 33.8 (10.3)	0.63 3.21
	Service	1/2" lead 5/8" lead	25.6 (7.8) 3.3 (1.0)	0.99 0.29
	Total			**5.12**
T-3 (Full Replacement)	Kitchen faucet to service line entry to house	1/2" copper 3/4" copper 1" copper	6.5 (2.0) 28.2 (8.0) 11.5 (3.5)	0.30 2.50 1.86
	Service	1" copper 5/8" lead	23.6 (7.2) 59.1 (18)	3.83 4.28
	Total			**12.77**
T-4 (Partial Replacement)	Kitchen faucet to service line entry to house	1/2" copper 1/2" galvanized	26.2 (8.0) 6.5 (2.0)	1.21 0.39
	Service	1/2" lead	62.3 (19.0) [49.2 (15.0) replaced]	2.41
	Total			**4.01**

Results

Water Quality Parameters. A source water sample was collected at each site on the day of lead service line replacement and analyzed for a variety of water quality parameters. Results are shown in Table F.34. In general, source water quality was very consistent, with little variation in the anions and cations measured.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Analysis of chlorine concentration, conductivity, pH, and temperature were performed on-site, and are displayed in Tables F.35 through F.38. Results were consistent within and between sites, with the exception of temperature and total chlorine residual which fluctuated during the course of the sampling. In addition oxidation-reduction potential measurements were also conducted on-site from one flowing water sample taken immediately before the lead service line was replaced. Figure F.49 displays these measurements.

Table F.34
Source Water Quality Results – Toronto

Parameter	Average	Min	Max
Ca, mg/L	36	34	38
Cl, mg/L	27	25	28
K, mg/L	2	2	2
Mg. mg/L	9	8	9
Mn, mg/L	<.002	<.002	<.002
Na, mg/L	12	12	13
SO4, mg/L	31	30	32
TOC, mg/L	3	2	3
Al, ug/L	71	41	164
Fe, ug/L	35	5	97

Table F.35
Site T-1 Water Quality

Sample Collection Relative to Lead Service Line Replacement	pH (pH Units)	Temperature (deg. C)	Free Chlorine (mg/L)	Total Chlorine (mg/L)	Conductivity (umhos/cm)
Before	7.25	19.5	0.05	0.76	316
Day of LSLR (immediately before)	7.23	9	0.03	1.02	313
1 Day After	7.32	19.6	0.04	0.67	311
2 Days After	7.22	19.2	0.06	0.75	311
3 Days After	7.4	18.3	0.05	0.69	314
1 Month After	7.39	22.2	0.03	0.64	309
2 Month After	7.4	23.7	0.06	0.72	316

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.36
Site T-2 Water Quality

Sample Collection Relative to Lead Service Line Replacement	pH (pH Units)	Temperature (deg.C)	Free Chlorine (mg/L)	Total Chlorine (mg/L)	Conductivity (umhos/cm)
Before	3.4	23.4	0.09	0.12	315
Day of LSLR (immediately before)	7.52	16.6	0.08	1.15	314
1 Day After	7.45	20.2	0.06	0.87	312
2 Days After	7.4	21.2	0.06	0.81	308
3 Days After	7.51	22.1	0.07	0.98	316
1 Month After	7.56	19.4	0.03	0.97	312
2 Month After	7.45	22.2	0.03	1.01	321

Table F.37
Site T-3 Water Quality

Sample Collection Relative to Lead Service Line Replacement	pH (pH Units)	Temperature (deg. C)	Free Chlorine (mg/L)	Total Chlorine (mg/L)	Conductivity (umhos/cm)
Before	7.55	19.2	0.06	0.98	316
Day of LSLR (immediately before)	7.42	14.1	0.07	1.19	313
1 Day After	7.52	20.1	0.08	1	315
2 Days After	7.48	22.1	0.06	0.87	317
3 Days After	7.5	22	0.1	0.94	323
1 Month After	7.56	20.1	0.03	0.74	311
2 Month After	7.58	23.1	0.02	1	334

Table F.38
Site T-4 Water Quality

Relation to Lead Service Line Replacement	pH (pH Units)	Temperature (deg. C)	Free Chlorine (mg/L)	Total Chlorine (mg/L)	Conductivity (umhos/cm)
Before	7.48	21.1	0.01	0.17	328
Immediately Before	7.52	11.5	0.05	1.15	304
1 Day After	7.47	21.9	0.02	0.28	316
2 Days After	7.46	24.3	0.03	0.67	334
3 Days After	7.48	23.7	0.01	0.3	323
1 Month After	7.6	26.2	0.01	0.71	312
2 Month After	7.46	24.7	0.01	0.13	322

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

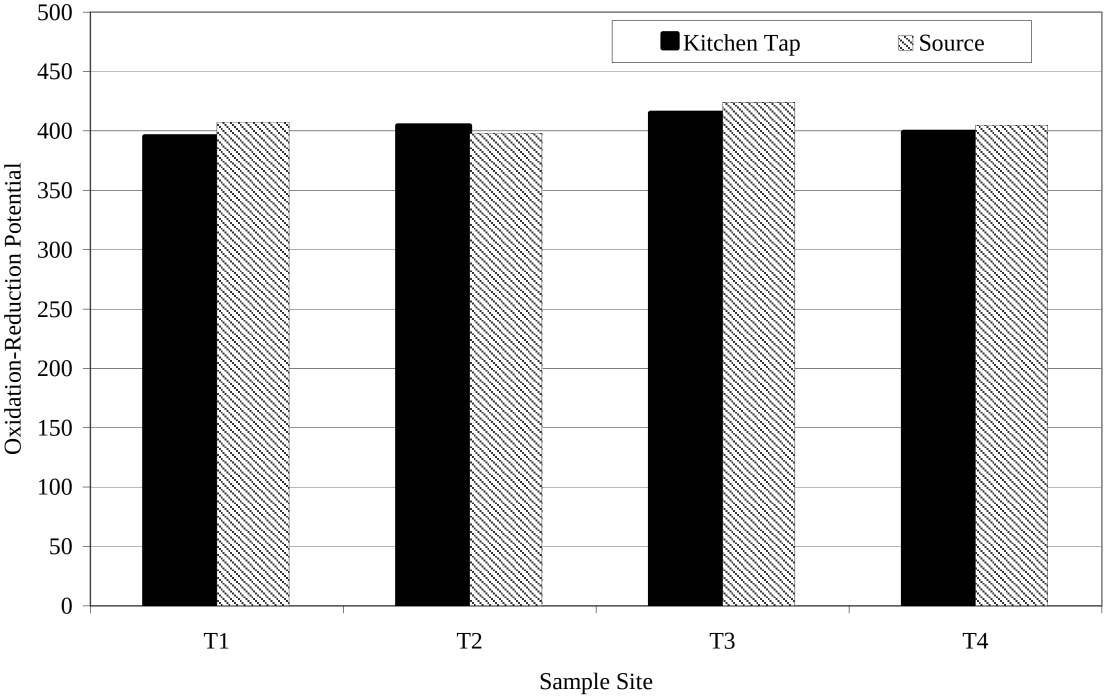


Figure F.49 Oxidation/Reduction Potential for Toronto LSLR Sites

Before the LSL replacements, alkalinity, HPC, and copper and zinc levels were measured on stagnation samples collected at the tap. Results are shown in Table F.39 Results varied by site, however alkalinity was relatively consistent (approximately 85 mg/L as $CaCO_3$).

Table F.39
Water Quality from Stagnation Samples at Toronto

Site	Alkalinity mg/L as CaCO3	Cu ug/L	HPC cfu/mL	Zinc ugL
T1	84	-	203	-
T2	84	55	595	26
T3	84	14	104	0
T4	88	27	281	13

Lead Levels. Total and dissolved lead levels were measured from the sequential volumes of water collected at the tap during multiple sampling events at each site to obtain a profile of lead concentrations through each site's plumbing system. Results from the first five stagnation samples were also combined to determine a calculated 1 liter lead level result for all sample rounds. In addition, 1 liter flushed samples were collected at the tap and analyzed for total and dissolved lead levels on the day of replacement. Samples were collected immediately before replacement (after flushing the water for 15 minutes), during replacement, and again after replacement and flushing for 15 minutes.

Figures F.50 through F.53 display the total and dissolved lead levels measured immediately before and after the LSL replacement. Site T-1 exhibited high particulate lead on the day of replacement. Total and dissolved lead level results for stagnation samples collected before and for up to 2 months after LSL replacement are displayed in Figures F.54 through F.61. With the exception of initial samples collected for the first 3 days after replacement at Site T-4, the majority of lead measured was in the dissolved form. At site T-1 (full LSLR), initial 125 and 250 mL sample volumes all exhibited total lead levels below the U.S. action level of 15 µg/L prior to LSL replacement, however, the impact of the lead service line is clearly indicated by the elevated lead levels measured from samples collected from the 3rd through 6th liters of water collected at the tap. After LSL replacement, total lead levels in the first five sequential samples collected at the tap were similar or lower than levels measured before replacement. Total lead levels measured in samples representative of the lead service were higher for the 3 days after replacement when compared to lead level measured from these samples before the lead service was replaced. By 1 month after replacement, total lead levels were lower than levels measured before replacement. At Site T-2, all sample volumes exhibited total lead levels below the action level of 15 µg/L prior to replacement. After LSL replacement, lead levels were elevated for up to 2 days, but by the third day were similar to levels measured before replacement.

For Site T3, with the exception of one sample collected 3 days after LSL replacement, all samples collected after replacement exhibited total lead levels lower than lead levels measured prior to replacement. The first four samples collected at the tap prior to replacement at Site T-4 were higher than 15 ug/L. After LSL replacement, samples representing the home piping exhibited high particulate lead for up to 3 days after replacement when compared to levels measured before replacement. Samples collected after replacement that represented the service generally exhibited total lead levels lower than lead levels measured prior to replacement.

Background lead levels measured in fully flushed samples were low (Figure F.62 through F.65). Calculated first liter lead levels were all below the U.S. action level of 15 ug/L at sites T-1 and T-2, and levels calculated after replacement were similar to levels calculated prior to replacement (Figure F.66 and F. 67). At Site T-3, calculated first liter lead results for up to three days after replacement were similar or higher than lead levels before, but were lower by 1 and 2 months after (Figure F.68). The partial lead service line replacement at site T-4 showed no improvement in calculated first liter lead results, even by 2 months after replacement. Significantly higher first liter lead levels were calculated for the 3 days immediately after the partial replacement (Figure F.69).

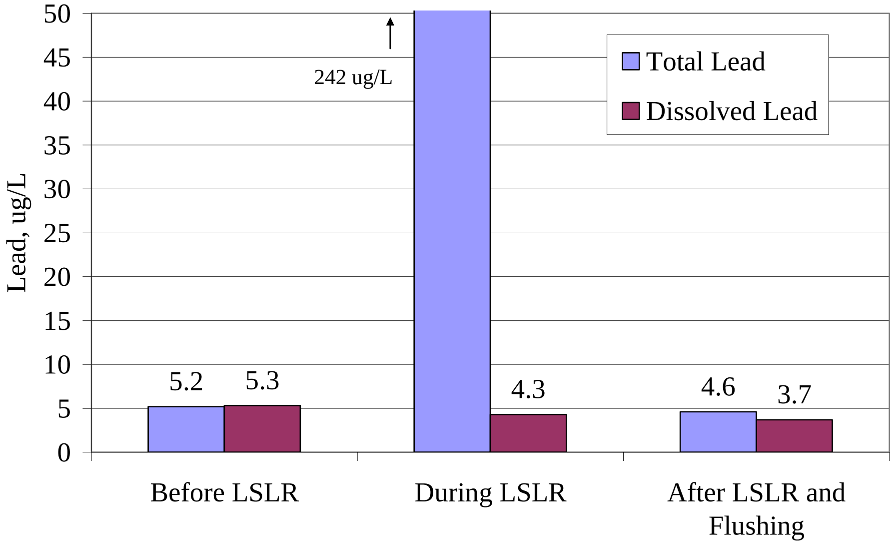


Figure F.50 Lead Levels Measured During LSL Replacement at Site T-1 (flushed)

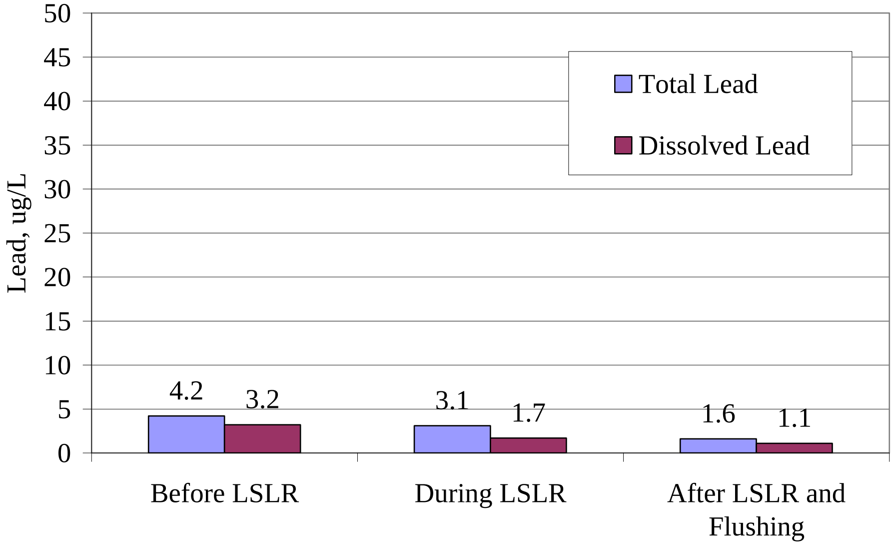


Figure F.51 Lead Levels Measured During LSL Replacement at Site T-2 (flushed)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

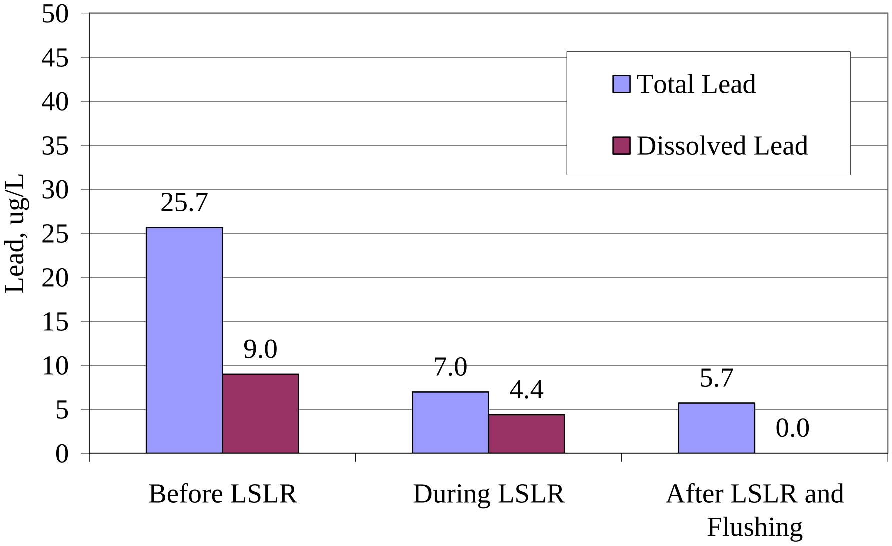


Figure F.52 Lead Levels Measured During LSL Replacement at Site T-3 (flushed)

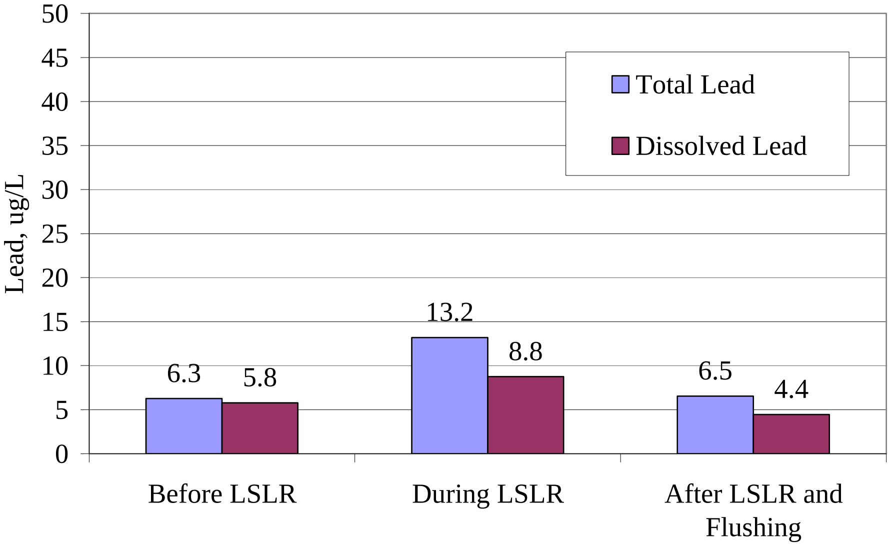


Figure F.53 Lead Levels Measured During LSL Replacement at Site T-4 (flushed)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

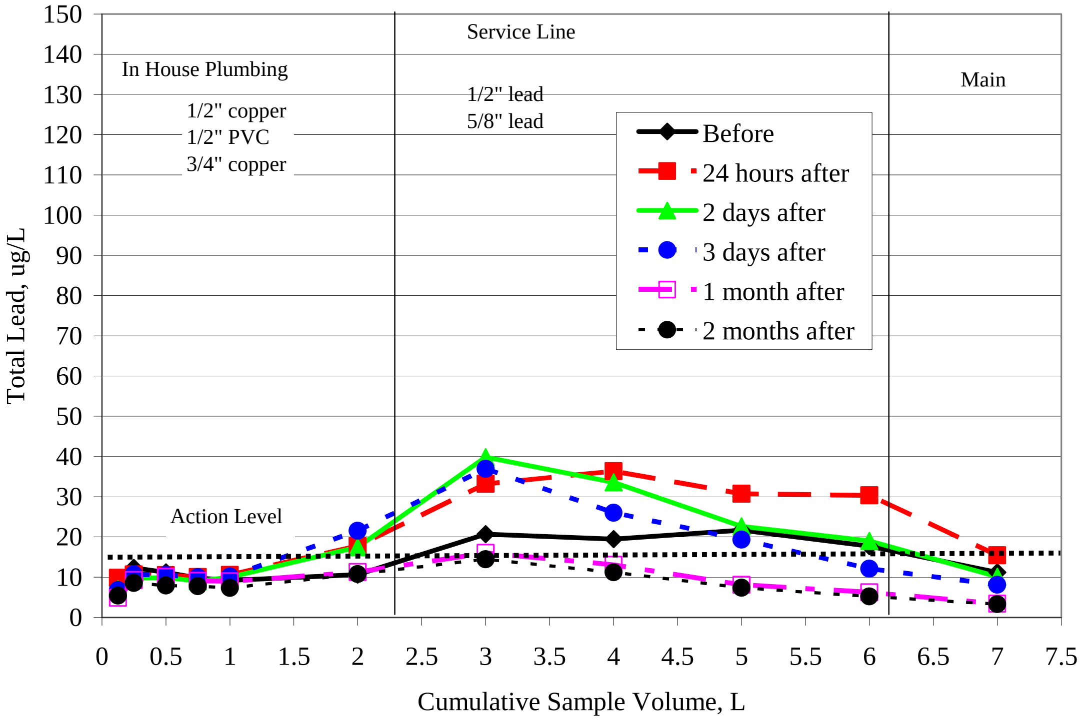


Figure F.54 Site T-1 Total Lead Concentration Profiles (stagnation)

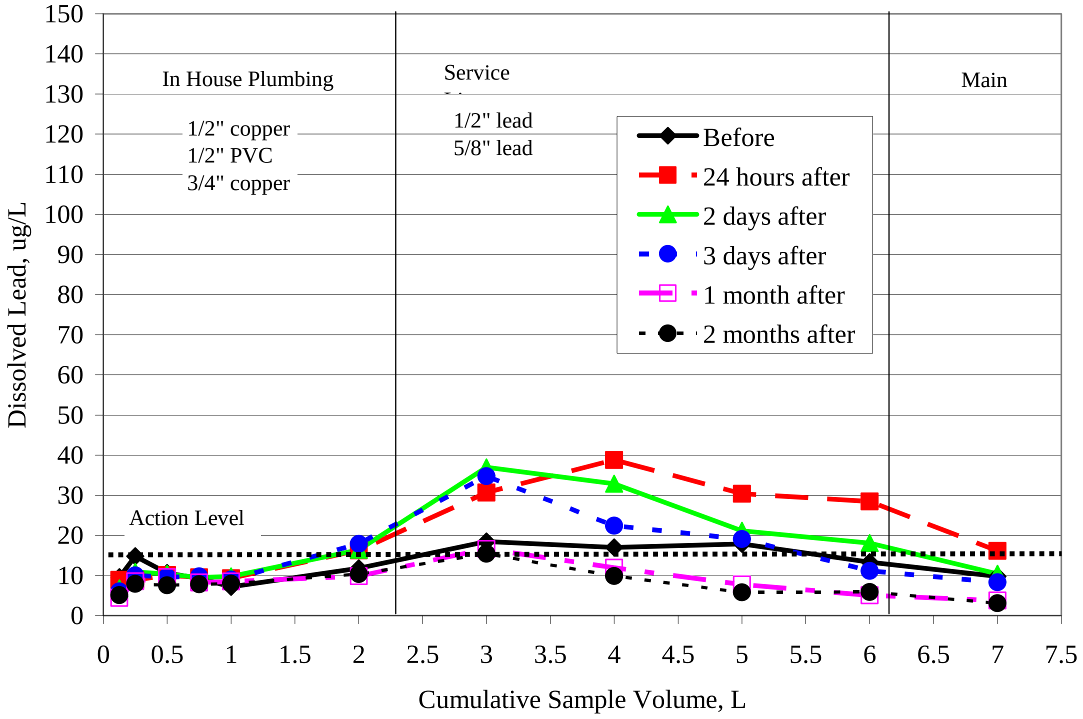


Figure F.55 Site T-1 Dissolved Lead Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

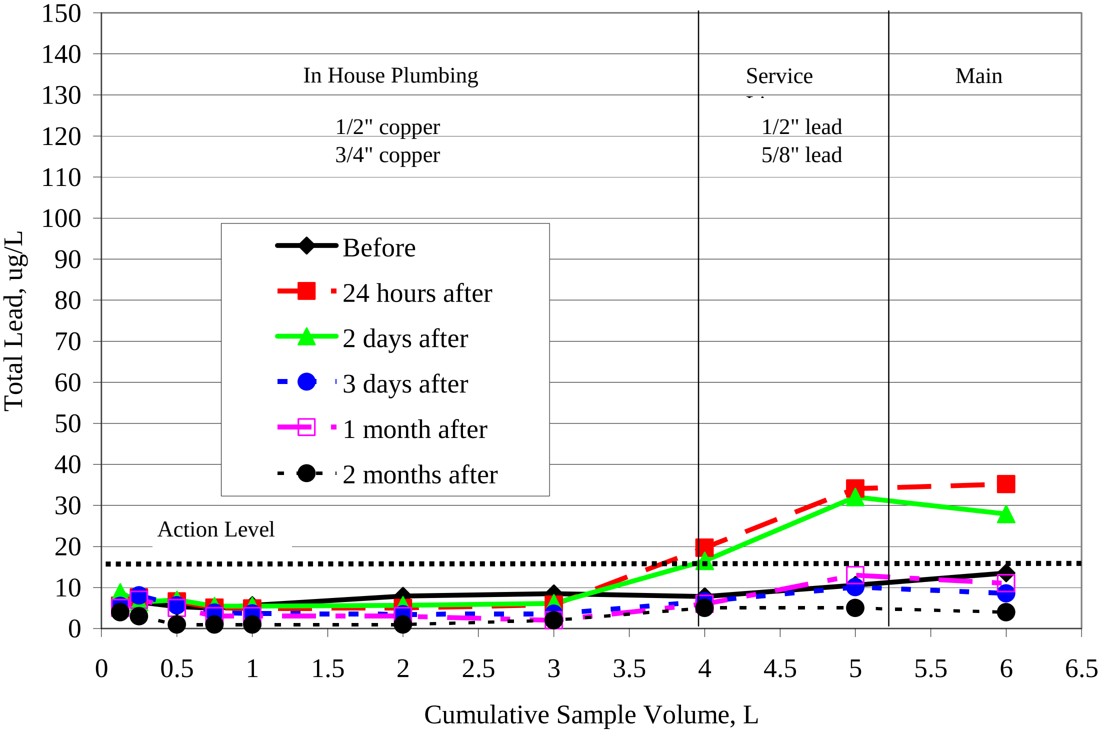


Figure F.56 Site T-2 Total Lead Concentration Profiles (stagnation)

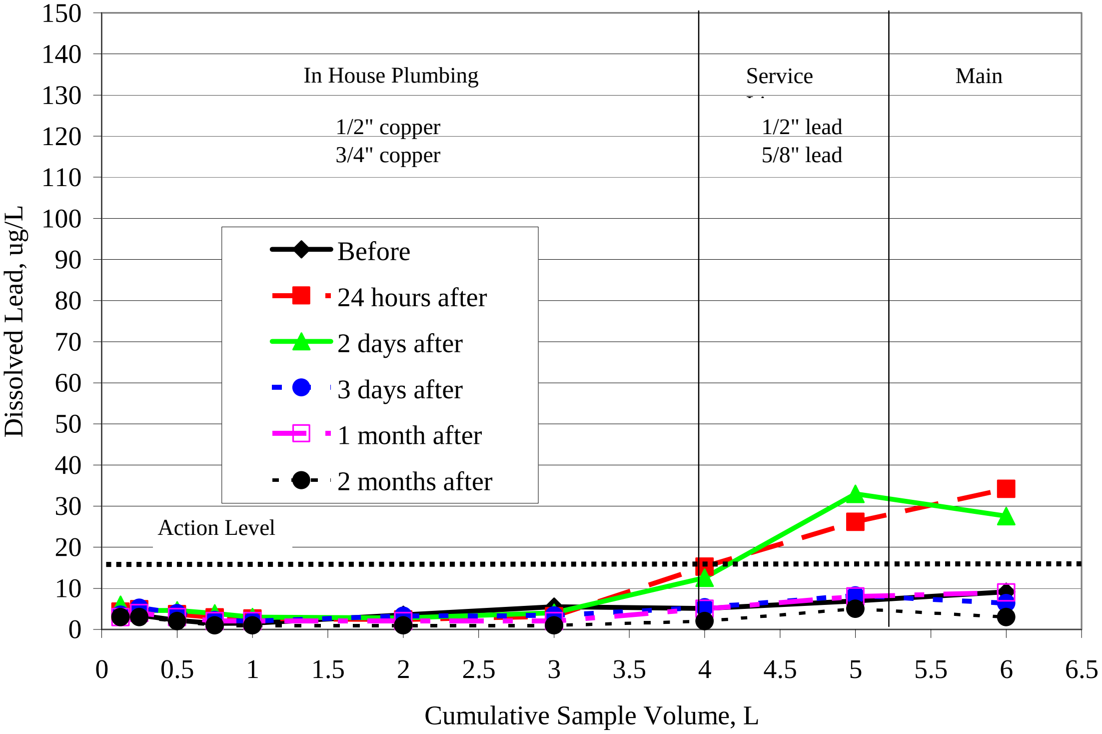


Figure F.57 Site T-2 Dissolved Lead Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

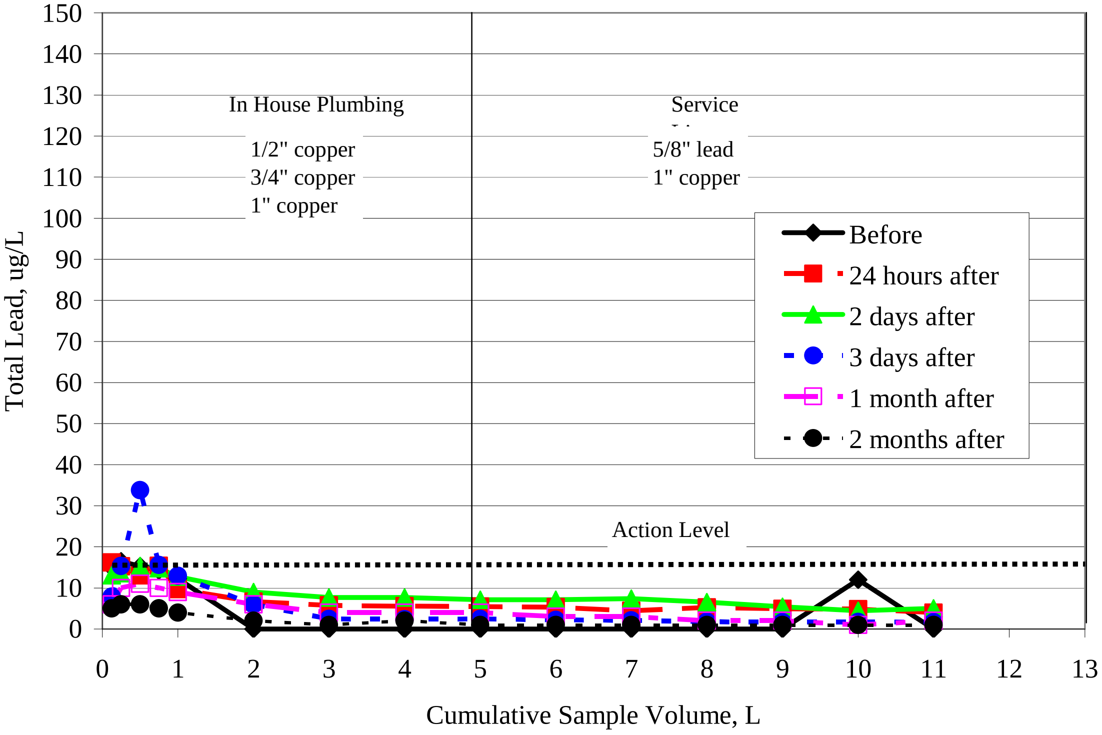


Figure F.58 Site T-3 Total Lead Concentration Profiles (stagnation)

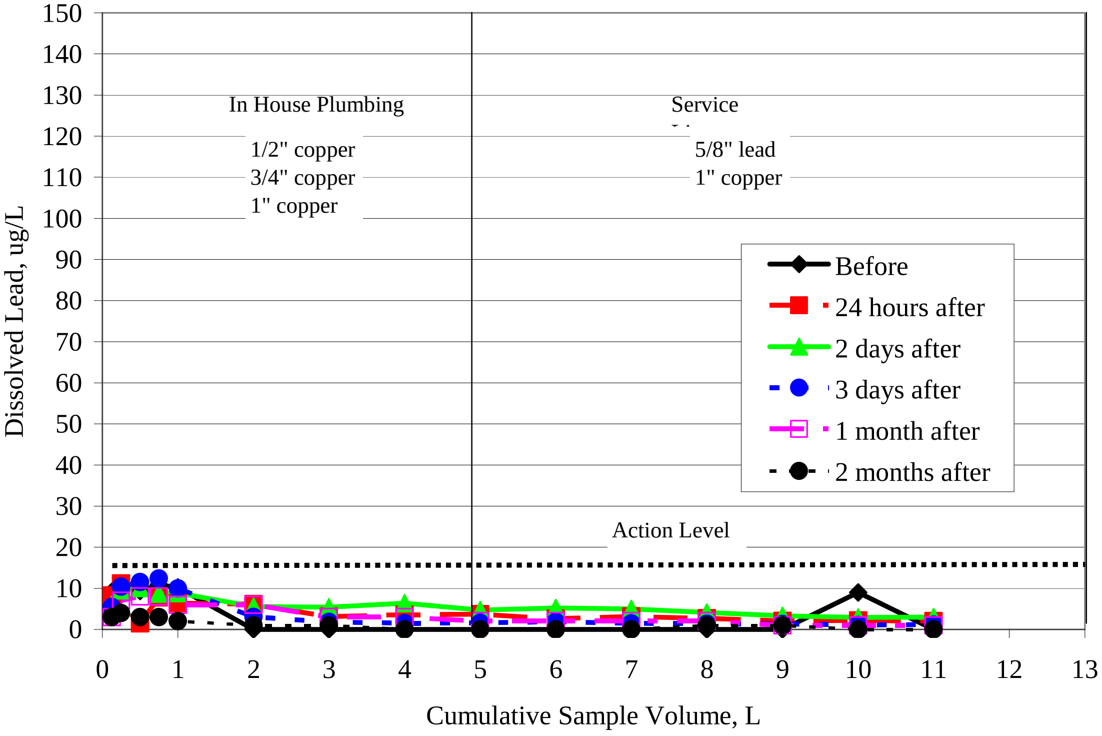


Figure F.59 Site T-3 Dissolved Lead Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

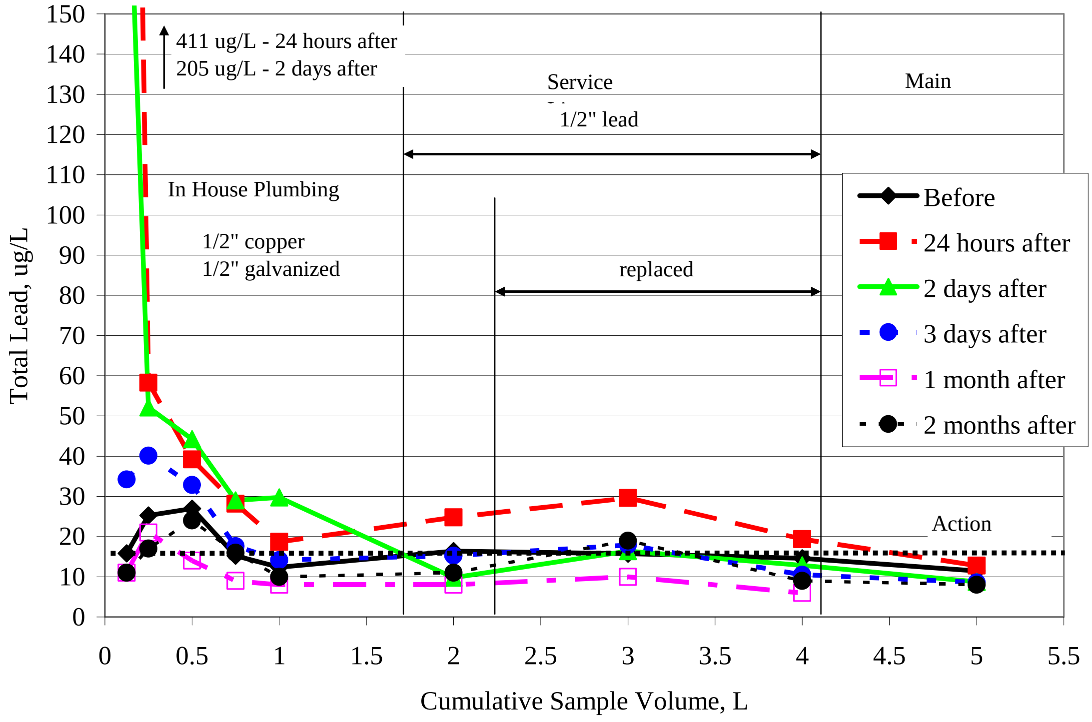


Figure F.60 Site T-4 Total Lead Concentration Profiles (stagnation)

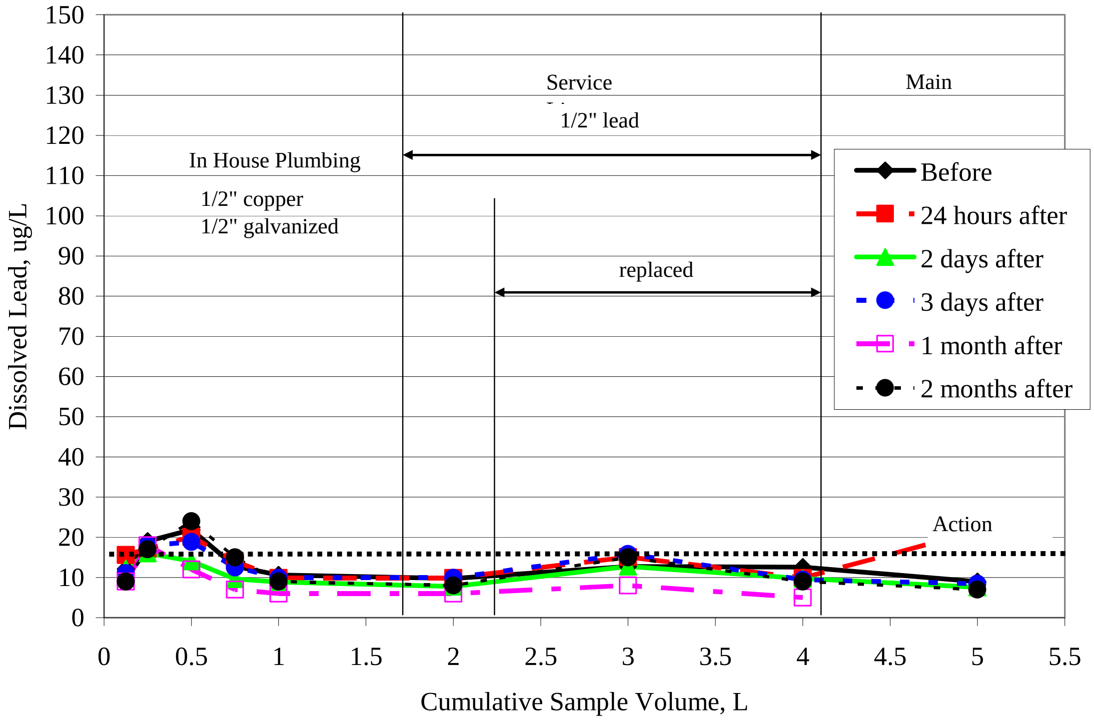


Figure F.61 Site T-4 Dissolved Lead Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

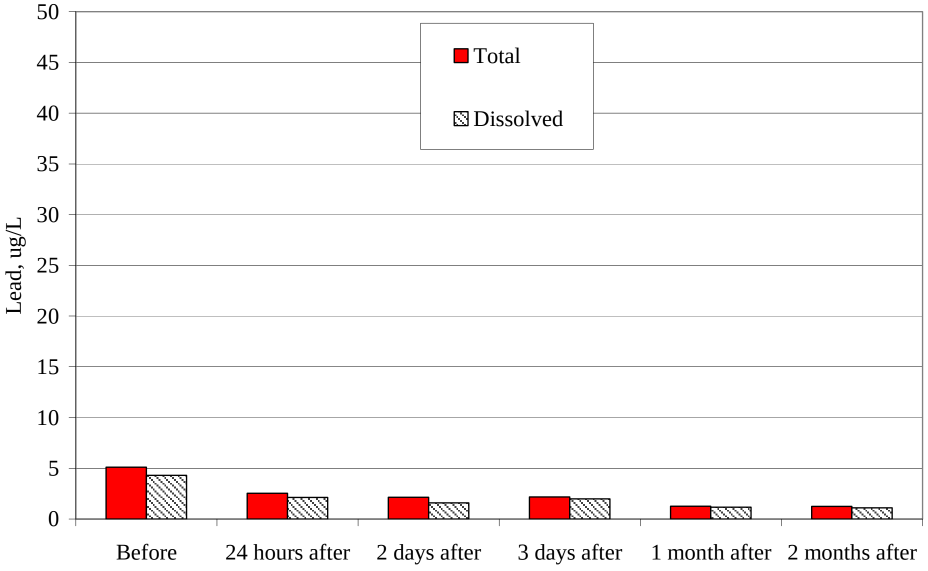


Figure F.62 Site T-1 Total and Dissolved Lead from Flushed Samples

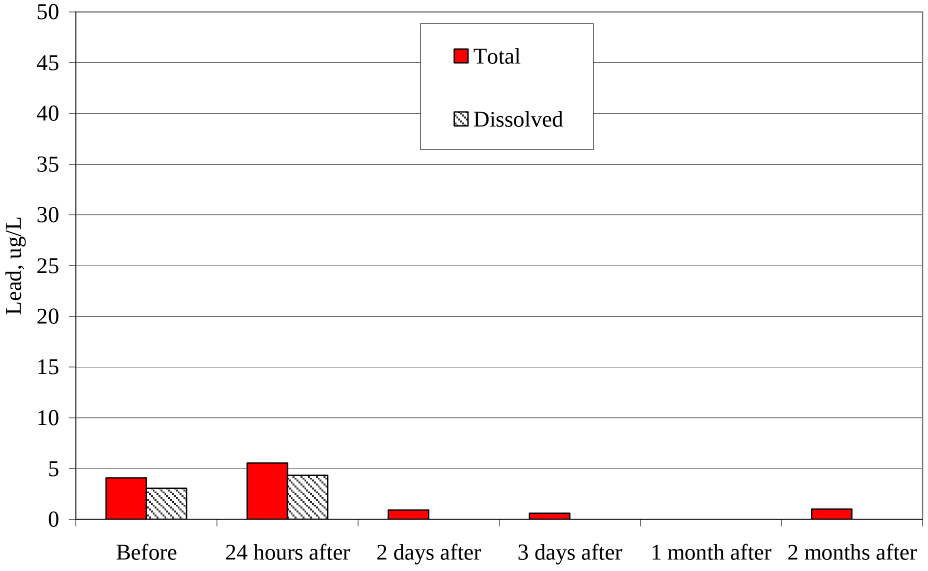


Figure F.63 Site T-2 Total and Dissolved Lead Levels from Flushed Samples

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

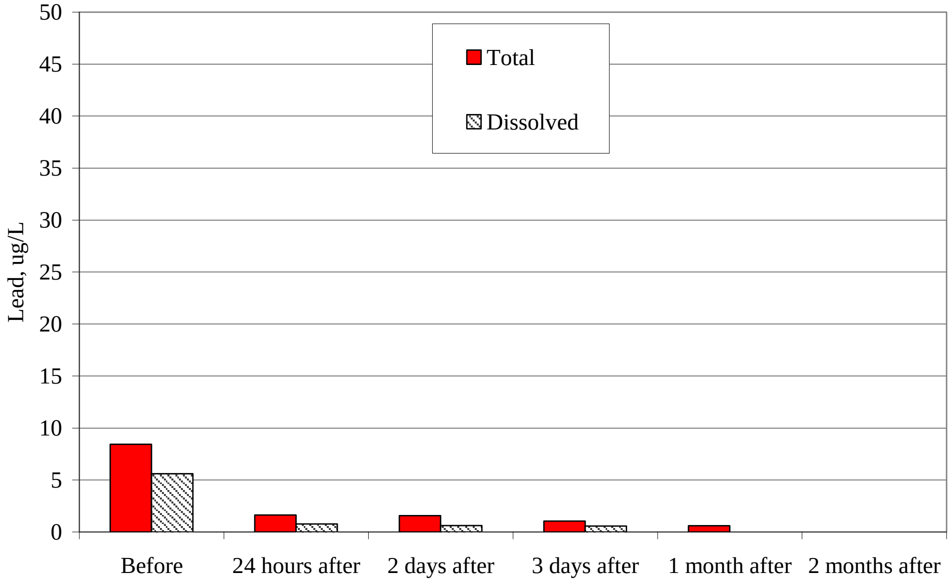


Figure F.64 Site T-3 Total and Dissolved Lead Levels from Flushed Samples

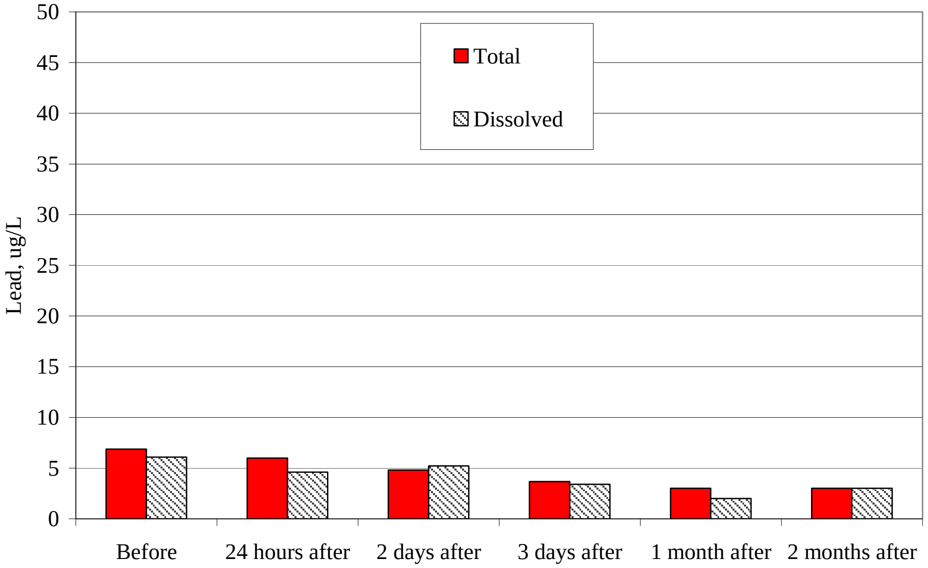


Figure F.65 Site T-4 Total and Dissolved Lead Levels from Flushed Samples

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

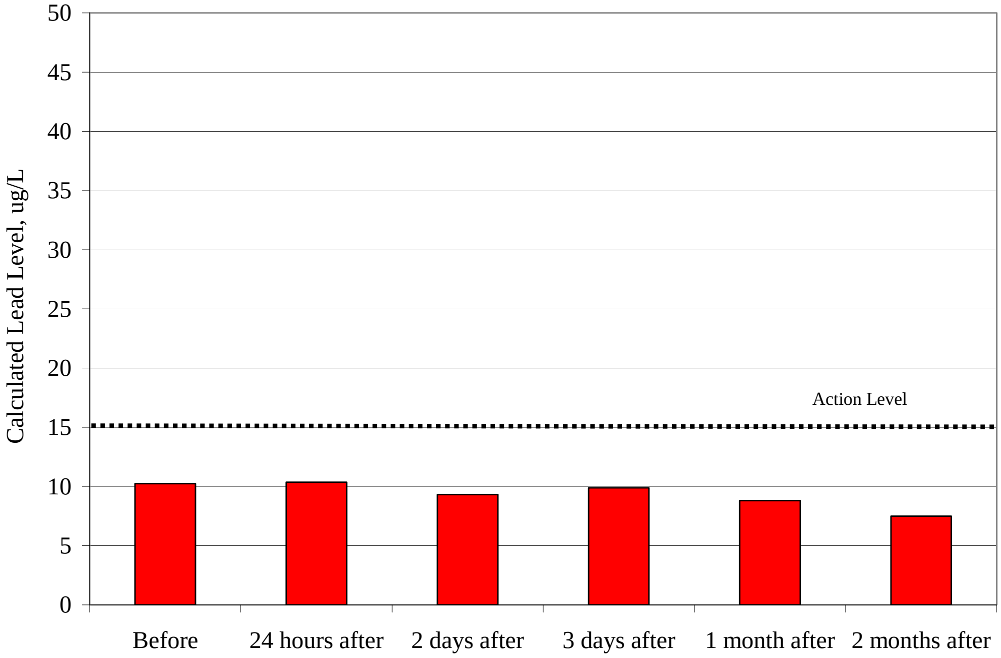


Figure F.66 Site T-1 Calculated First Liter Lead Levels (stagnation)

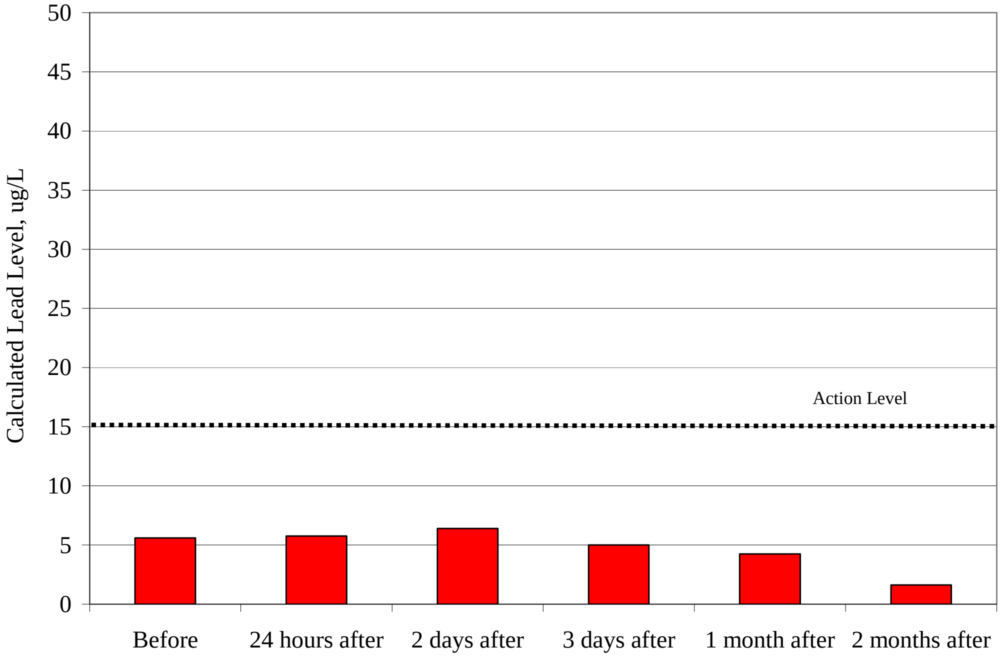


Figure F.67 Site T-2 Calculated First Liter Lead Levels (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

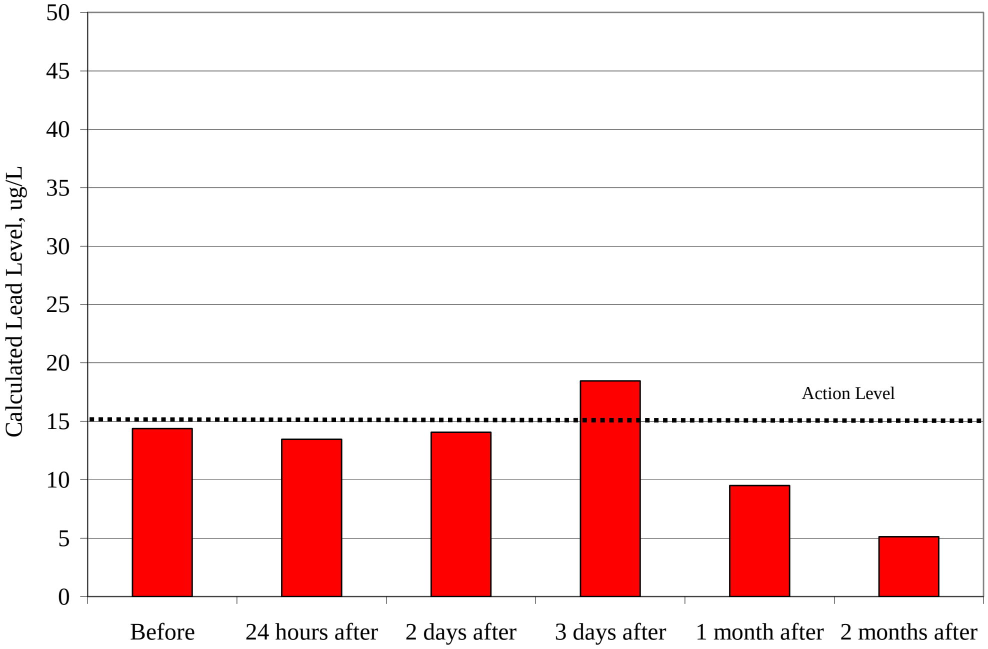


Figure F.68 Site T-3 Calculated First Liter Lead Levels (stagnation)

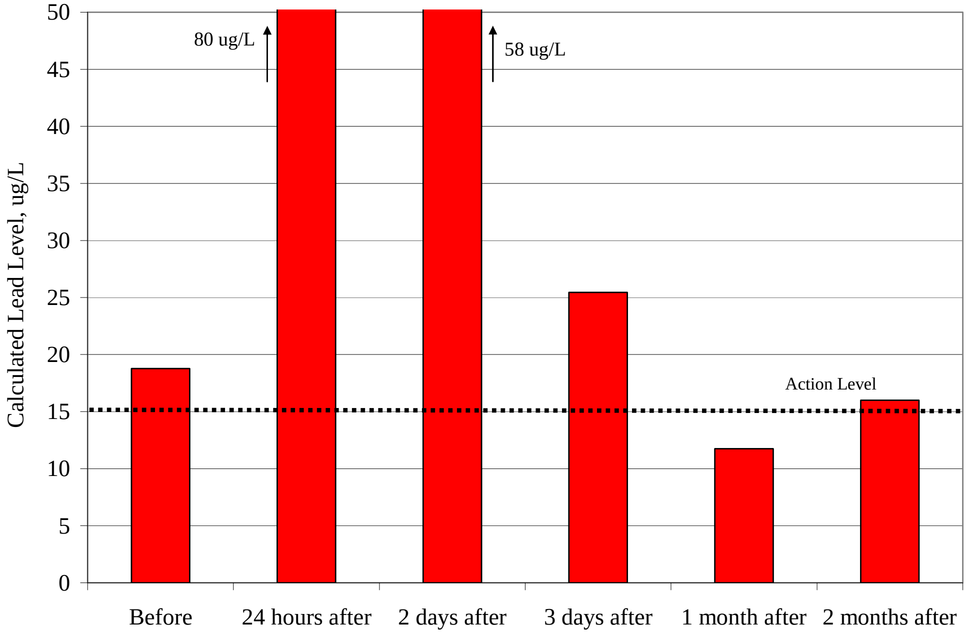


Figure F.69 Site T-4 Calculated First Liter Lead Levels (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scale Analyses. Scale mineralogy and scale chemistry of samples from the four lead service lines (Table F.40) showed little variation between sites, similar to the pre-removal water chemistry. The scales were simple in structure and composition, comprising hydrocerussite as the only significant lead mineral, plus an amorphous aluminum hydroxide with a small amount of iron oxyhydroxide forming a surface layer. The aluminum and iron compounds were found on both lead and brass plumbing components, but the hydrocerussite is confined to the lead components. Unlike scales from other utilities investigated, the Toronto scales lack manganese, but were very high in aluminum.

Table F.40
Samples Received from Toronto for Scale Analysis

Locality	Samples	Materials	Pipe size, O.D.
T-1 Site W	11_PP01	Pb pipe	1 1/8 “
	11_PP02	Pb pipe	1 1/8 “
T-2 Site C	11_PP03	Pb pipe	1 “
	11_PP04	Pb pipe	1 “
T-3 Site G	11_PP05	Pb pipe	1 “
	11_PP06	Pb pipe	1 “
T-4 Site L	11_PX07	Pb pipe with brass fittings	7/8 “
	11_VB07	Brass valve (curb stop)	

Scale properties. Appearance. The scales from each site were remarkably similar in appearance, in contrast to scales from most utilities, which show considerable variation. In addition, the scales were similar in texture and color on both lead and brass components (Figure F.70 through F.72).

Figure F.70 Lead to Brass transition at Site T-4. The scale comprises a thick, white lower layer and a thin brown-red upper layer on both lead and brass components.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

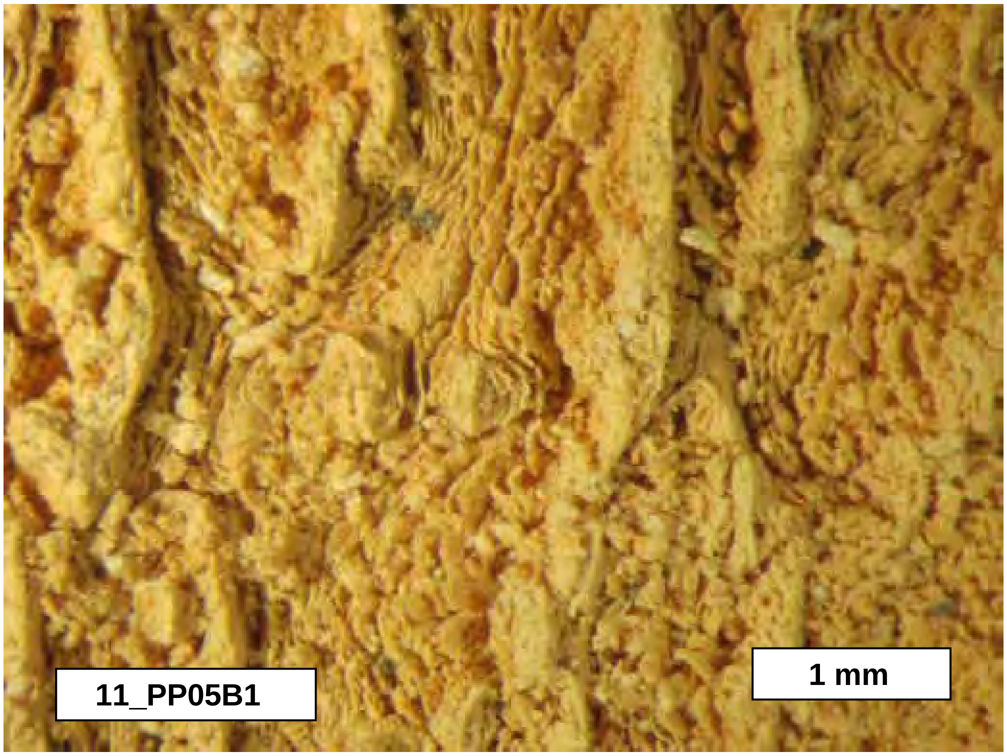


Figure F.71 Close up View of Scale Surface on a Lead Pipe from Site T-3

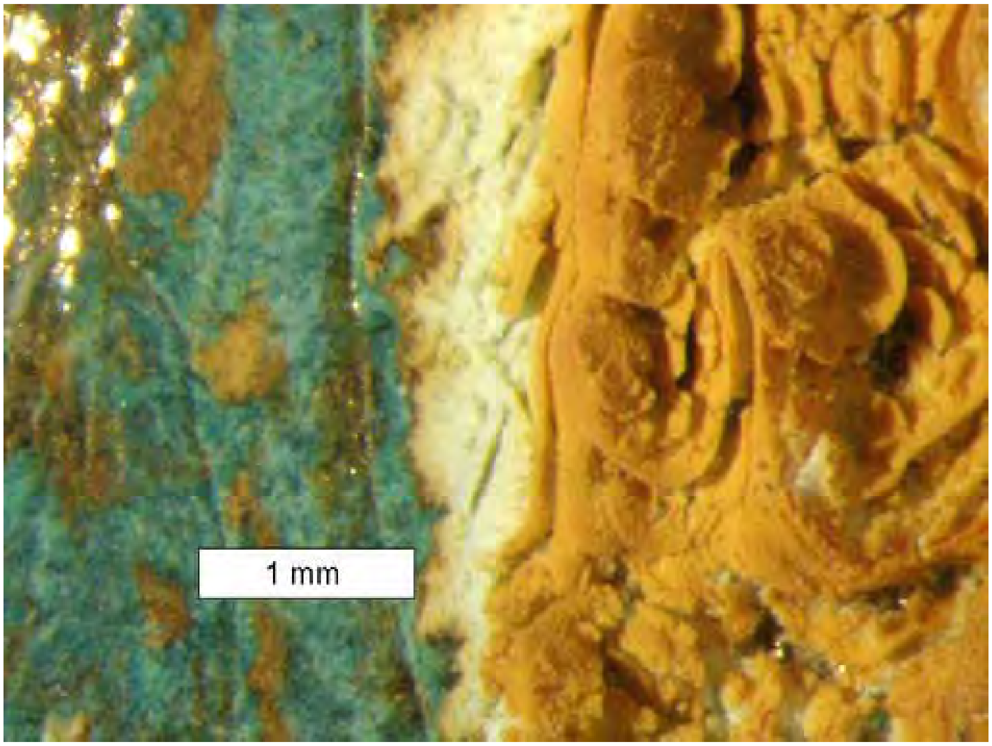


Figure F.72 Close up view (20x) of Scale on a Brass Valve from Site T-4. The initial scale formed is a thin layer of copper carbonate, followed by an amorphous aluminum hydroxide layer and a very thin iron hydroxide layer.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scale properties. Elemental analyses. Scale chemistry was simpler for Toronto than for other utilities. Compositions were relatively uniform from site to site, but were unusual in showing very high aluminum values. Appreciable Fe was also present, suggesting an amorphous $Fe(OH)_3$ phase, based on the XRD results and the reddish-orange color. Manganese (Mn) was quite low compared to other utilities. There is, in common with many other utilities, appreciable Ca, suggesting the presence of some $CaCO_3$ in the scales, although no calcite was seen in the XRD spectra.

Water chemistry did not appear to be related to scale chemistry in any obvious way. Note that total Pb in the water was actually inversely related to Pb content of the scale. The exception was Fe, which was closely correlated in the scale and the water analyses (Table F.41).

Table F.41
Chemistry of Toronto Scales and Corresponding Water Chemistry
(average of Layer 1 + Layer 2)

Chemistry of Scales (average of Layer 1 and Layer 2)

Element	% Pb	% Zn	% Cu	% Al	% Fe	% Mn	% Ca	% K	% S	% P	% Si
T-1	13.9	0.01	0.04	21.3	14.0	0.01	5.34	0.02	0.06	0.76	3.29
T-2	45.4	0.00	0.02	7.77	12.3	0.03	2.51	0.01	1.42	0.41	1.57
T-3	52.1	0.01	0.03	8.16	10.7	0.30	3.54	0.04	1.60	0.45	2.16
T-4	21.8	0.10	1.42	17.1	7.70	0.20	6.76	0.10	0.75	0.72	3.31

Average water chemistry pre-removal

Element	µg/L Pb, total	µg/L Zn, total	µg/L Cu, total	µg/L Al, total	µg/L Fe, total	mg/L Mn	mg/L Ca	mg/L K	mg/L SO4	mg/L PO_4	mg/L Si
T-1	15.84	23.3	151	58	97	<.002	34	1.5	30.8	n.d.	0.44
T-2	8.95	12.0	49.5	60	49	<.002	35	1.7	31.7	n.d.	0.41
T-3	10.98	9.5	67.8	89	49	<.002	36	1.9	32.4	n.d.	0.39
T-4	15.37	11.5	65.8	49	30	<.002	35	1.8	30.9	n.d.	0.56

n.d. = not determined; total indicates total metals (dissolved plus particulate)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scale properties. Mineralogy. X-ray diffraction analyses indicates that all the scale samples from lead pipes were dominated by hydrocerussite, with minor cerussite as the only Pb minerals (Figure F.73). The upper layer (L1) has much smaller hydrocerussite peaks than the lower (L2), and sometimes shows an additional peak around 17 degrees that corresponds most closely to the mineral gibbsite. The peak is very broad, however, and none of the other gibbsite reflections were seen, suggesting that the phase is nearly amorphous. No peaks for Fe minerals were found in the upper layer, despite its rusty color. Thus the lower layer is dominated by crystalline hydrocerussite, whereas the upper layer is dominated by amorphous to poorly crystalline Al and Fe hydroxides. Scales on the brass components contain only the Al and Fe components and were X-ray amorphous.

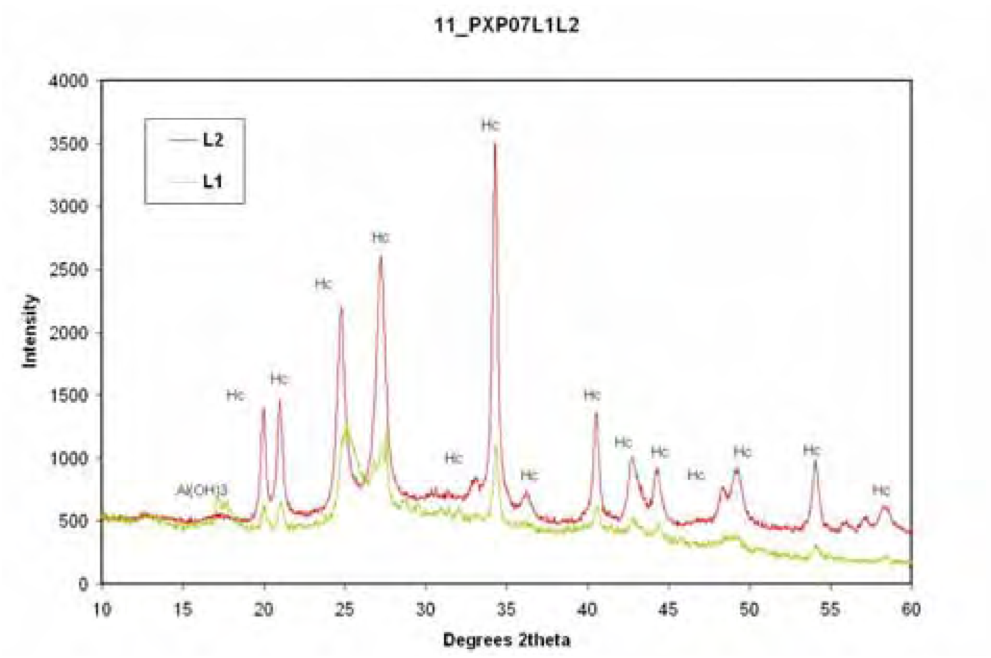


Figure F.73 Representative x-ray Diffraction Pattern from Toronto Pipe Scales

Examination of the scales by micro-Raman laser spectroscopy confirms the interpretations of mineralogy from XRD. The upper layer is amorphous, whereas the lower layer comprises hydrocerussite with secondary cerussite (Figure F.74 and F.75)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

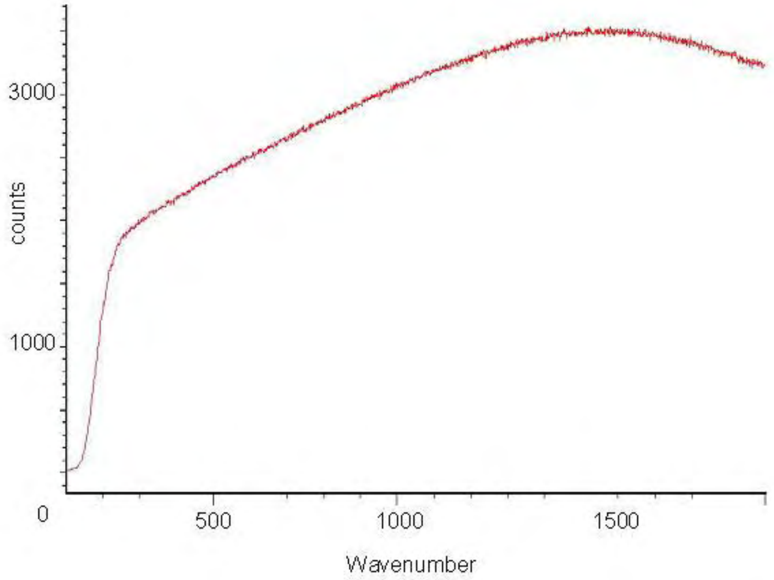


Figure F.74 Raman spectrum of Sample 11_PP01 Showing Broad Amorphous Peak of the Al-rich Surface Layer.

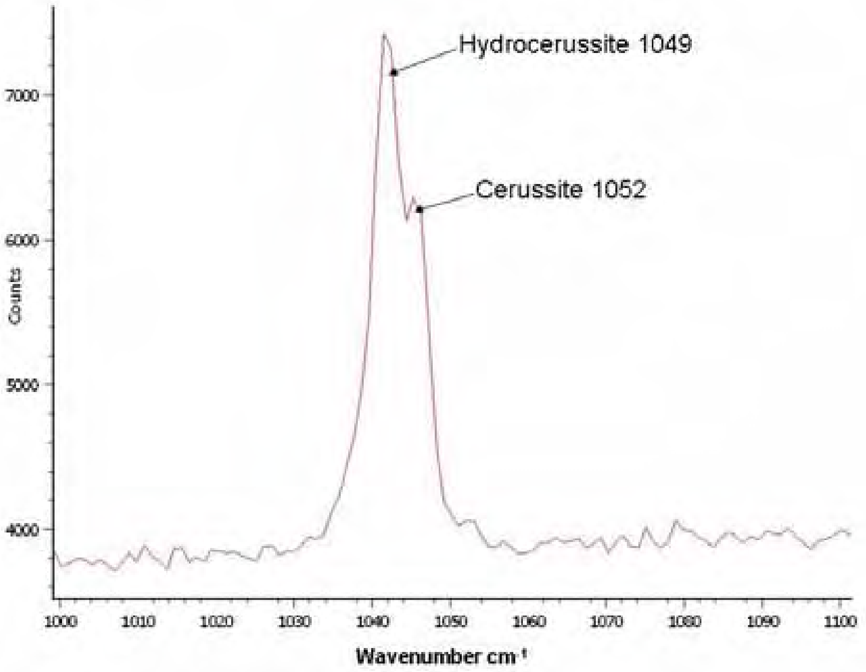


Figure F.75 Enlargement of the Raman Spectrum of the Lead Carbonate Region from 11_PP01L2 (Site T-1) Showing Predominance of Hydrocerussite with Minor Cerussite.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Figures F.76 through F.79 display the SEM photos of copper carbonate and Al hydroxide grains found on the brass valve removed from site T-4.

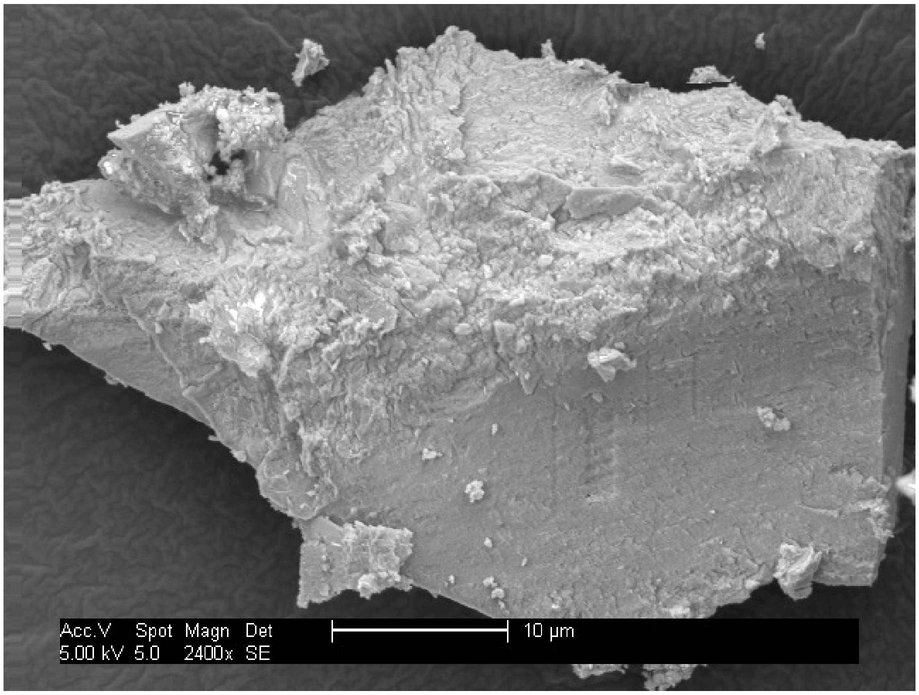


Figure F.76 Copper Carbonate Scale for Brass Valve VB07L1 (Site T-4)

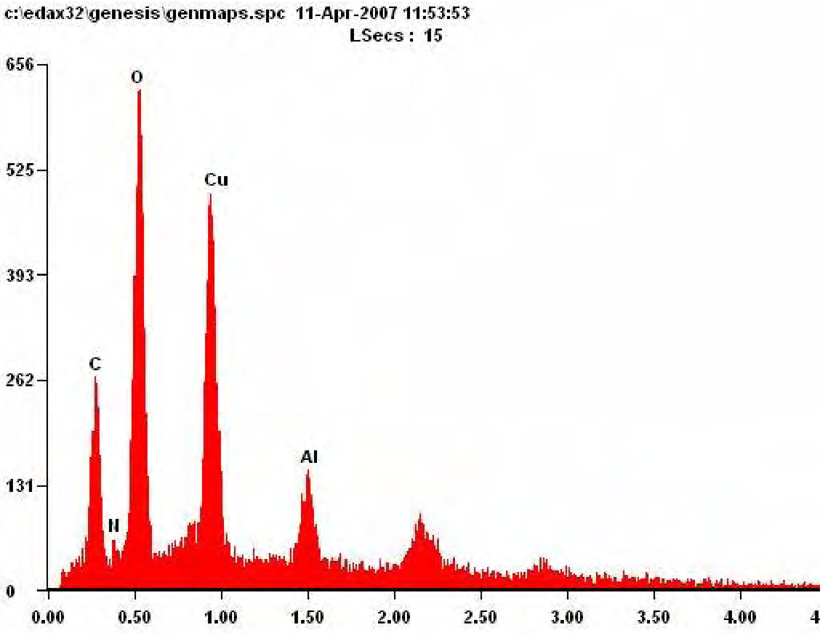


Figure F.77 EDAX trace for copper carbonate

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

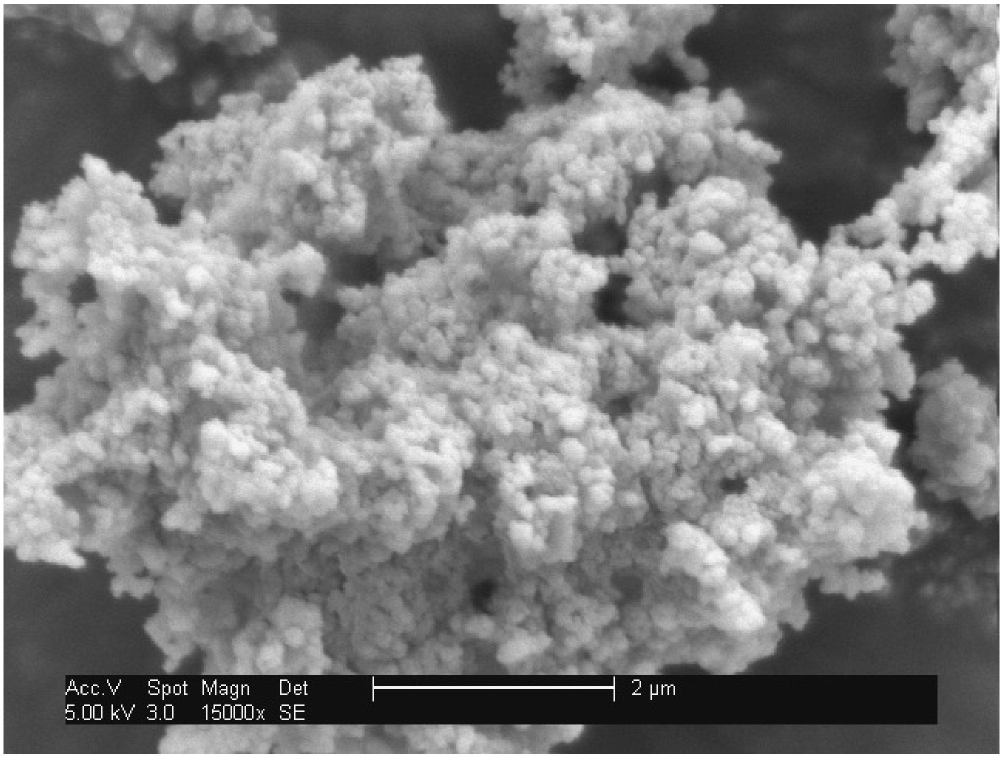


Figure F.78 Poorly crystalline, nanometer-sized Al hydroxide grains, brass valve VB07L1 (Site T-4).

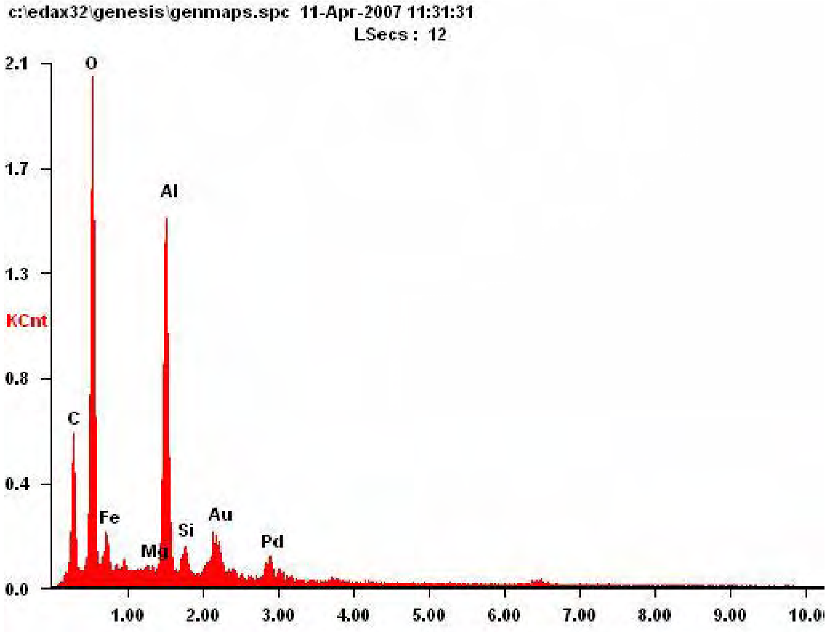


Figure F.79 EDAX spectrum of Al hydroxide scale. The carbon peak is from the carbon backing tape, Au and Pd from the sample coating procedure.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Correlation with Water Quality. The Pb content of the scales appears to be unrelated to the Pb content of the water (as measured before replacement of the service branches) (Table F.42). The best predictor of dissolved Pb release was temperature, followed by pH, which itself is closely related to temperature:

Table F.42
Pre-replacement Pb Releases Compared to Water Quality and Dominant Scale Components

Constituent	Temp oC	pH	Pb total µg/L*	Pb dissolved µg/L*	Pb particulate µg/L	Pb in scale, %	Al in scale, %	Fe in scale, %
T-1	9.0	7.23	15.8	13.9	1.97	13.9	21.3	14.0
T-2	16.6	7.52	8.95	5.35	3.61	45.4	7.77	12.3
T-3	14.1	7.42	11.0	8.19	2.79	52.1	8.16	10.7
T-4	11.5	7.52	15.4	11.8	3.56	21.8	17.1	7.70

*average value from sequential samples collected before LSLR

Although data is limited, dissolved Pb decreased as temperature and pH increased at these four sites, consistent with control by solubility of a Pb carbonate mineral (alkalinity was not well correlated to Pb release because it is essentially constant for all sites). Particulate Pb releases, however, were the converse of dissolved, rising with temperature and pH, as shown in Figure F.80. It is possible that this rise with pH is caused by dissolution of $Al(OH)_3$, which is more soluble at higher pH and temperature values. The dissolving Al may then destabilize the surface layer of the scale, permitting release of Pb-bearing particulates. However, there is no association of Al content of the water with dissolved or particulate Pb. Instead there is a strong positive correlation between dissolved Pb and scale Al content, the reason for which is not apparent.

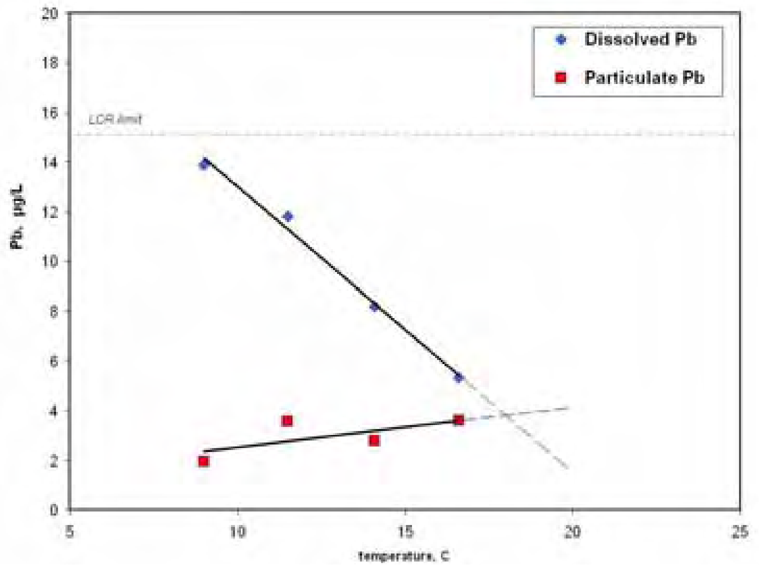


Figure F.80 Control of Pb Release by Temperature (prior to replacement). The steeper slope of the dissolved line results in a reduction of total Pb as temperature rises.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

PHREEQC Modeling. PHREEQC is a solution speciation-reaction model developed by the US Geological Survey that is widely used to model behavior of aqueous solutions in equilibrium with mineral phases. Input to the model is measured water chemistry. Several types of output can be specified. In this case the distribution of chemical species in the solution and the saturation state of the solution with respect to an array of possible mineral phases has been calculated. The saturation state, expressed as the degree of departure from equilibrium, is a useful predictor of scale behavior under changing water treatment conditions such as an increase in pH. Based on the scale mineralogy and chemistry determined by XRD, XRF, and SEM-EDAX, a set of likely scale phases was selected to check for saturation state.

The results on PHREEQC modeling showed that the water was in equilibrium with a poorly crystalline $Al(OH)_3$, in agreement with the XRD results. Crystalline FeOOH was too highly supersaturated to be the controlling Fe phase, which was more likely a totally amorphous $Fe(OH)_3$, again in agreement with XRD results. The water was strongly undersaturated with all Pb minerals, including hydrocerussite. Therefore Pb releases were perhaps not controlled by equilibrium dissolution of the hydrocerussite component of the scale, as suggested above, but by some set of kinetic factors, such as the protective covering of Al-Fe hydroxide on the surface of the scale (Table F.43).

Table F.43
Saturation Indices for Likely Minerals in the Toronto Scales

Mineral Site	Hydrocerussite $Pb_3(OH)_2(CO_3)_2$	Goethite FeOOH	Gibbsite $Al(OH)_3$	$Al(OH)_3$ amorphous $Al(OH)_3$	Malachite $Cu_2(OH)_2CO_3$
T-1	-2.61	4.81	1.51	-1.15	1.54
T-2	-3.31	5.04	2.40	-0.19	0.50
T-3	-2.95	4.87	1.70	-0.91	0.78
T-4	-2.28	4.66	1.41	-1.23	1.02

Lead levels versus scale composition prior to LSLR. The amount of lead measured at the tap may be related to the composition of the surface scale layer (Table F.44). Specifically, the higher the abundance of non-Pb components in the scale, the more Pb may be released. This effect could result from physical destabilization of the scale by incorporation of these other components.

Table F.44
Pb at the Tap and % Pb in Layer 1 of the Scale, Pre-replacement of Service Branch

		Pre-replacement		
Site	Pb total µg/L	Pb dissolved µg/L	Pb particulate µg/L	% Pb in scale L1
T-1	15.37	11.81	3.56	13.6
T-2	15.84	13.87	1.97	13.9
T-3	8.95	5.35	3.61	22.4
T-4	10.98	8.19	2.79	27.6

*average value from sequential samples collected before LSLR

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Boston Water and Sewer Commission

The Boston Water and Sewer Commission (BWSC) is the largest of 50 communities that receive drinking water from the Massachusetts Water Resource Authority (MWRA). The MWRA treats water from the Quabbin and Wachusett Reservoirs at the John J. Carroll Water Treatment Plant using ozone and chloramines for disinfection. Alkalinity and pH are adjusted for corrosion control using sodium carbonate and carbon dioxide. Table F.45 lists typical finished water quality characteristics for finished water from the plant.

Table F.45
Typical Finished Water Quality from Carroll WTP

Finished Water Quality Parameter (average from March 2007)	Value
pH, pH Units	9.6
Alkalinity, mg/L $CaCO_3$	40.2
Hardness, ppm	15.8
Conductivity, umhos/cm	198
Disinfectant residual, ppm (Chlormamines)	2.4 (total) 0.05 (free)
Total Trihalomethanes. ppb	4.9
Haloacetic Acids – 9, ppb	6.3

The BWSC has approximately 89,000 service lines in their system. Of these services, there are only approximately 1500 lead service pipes in place that extend from the main to the curbstop or meter, and are owned by BWSC. There are approximately 4500 lead service pipes in place that are privately owned which extend from the curbstop or meter to the residence. BWSC has implemented an aggressive lead service line replacement program in which they provide a $1000 credit towards the cost of privately owned lead service line replacement and a 24 Month Interest-Free Repayment Plan.

Site Information and Sample Collection

BWSC conducted lead service line (LSL) replacements for this project at four sites from August 2005 through September, 2006. At all sites, the utility portion of the service line from the property line to the main had already been replaced, so the replacements involved removal of the customer (private) side of the lead service line. A premise piping survey was conducted at each site prior to sampling to determine the material, length and diameter of pipe between the kitchen faucet and the beginning and end of the LSL. This data was used to calculate the water volume that must pass through the kitchen faucet to reach water in contact with the LSL during the stagnation period. Table F.46 lists the material, diameter, length, and volume of water contained in each section of piping from the thirteen.

The piping in the residences was generally 3/4" copper, however there was limited use of galvanized piping at three of the sites. Existing lead service lines were 3/4' or 1" in diameters, and lengths ranged from approximately 17 to 28 feet. Sampling consisted of an initial flushed sample (15 minutes +), followed by a series of sequential samples collected after the water was allowed to stagnate for a minimum of 6 hours.

Results

Water Quality Analyses. Analysis of free and total chlorine concentration, TDS or conductivity, pH, alkalinity, temperature, copper, zinc, and orthophosphate levels were performed on selected stagnation samples before and after replacement. Results are displayed in Tables F.47 through F.50. Results were consistent within and between sites, with the exception of temperature and total chlorine residual which fluctuated during the course of the sampling.

Lead Levels. Total and dissolved lead levels were measured from the sequential volumes of water collected at the tap during multiple sampling events at each site. In this way, a profile of lead concentrations through the site's plumbing system was obtained. Results from the first five stagnation samples collected were also combined to determine a calculated 1 liter lead level result. Flushed samples were also collected on the day of replacement, both immediately before replacement (after 15 minutes flushing), and after replacement and flushing for 15 minutes.

Table F.46
Site Survey Information for BWSC

Site No.	Location	Piping	Pipe Length, feet	Volume, L
B-1 (Full Replacement)	Kitchen faucet to service line entry to house	3/8” copper	1.5	0.04
		1/2” threaded brass	10.25	0.47
		1/2” copper	5	0.23
		3/4” copper	33	3.14
	Service	3/4” lead	20.2	1.76
	Total			**5.64**
B-2 (Full Replacement)	Kitchen faucet to service line entry to house	3/4” copper	50.42	4.77
		3/8” galvanized	2.0	0.08
	Service	1” lead	17.5	2.70
	Total			**7.56**
B-3 (Full Replacement)	Kitchen faucet to service line entry to house	1/2”copper	27.8	1.28
		3/4” copper	17.4	1.65
		1/2” galvanized	2.7	0.16
	Service	3/4” lead	29	2.52
	Total			**5.61**
B-4 (Full Replacement)	Kitchen faucet to service line entry to house	1/2” copper	39	1.79
		3/4” copper	1.25	0.12
		1/2” galvanized	3.25	0.19
	Service	3/4” lead	28	2.44
	Total			**4.54**

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.47
Site B-1 Water Quality Data

Sample Collection Relative to Lead Service Line Replacement	pH	Temp. (deg. C)	Conductivity (umhos/cm)	Total Chlorine (mg/L)
Before	9.3	24.2	-	0.16
1 Day After	9.2	25.2	182.6	0.14
2 Days After	9.7	24.6	210	0.05
3 Days After	9.5	25.2	196.4	0.08
1 Month After	8.8	23.3	180.1	0.53
2 Month After	9.2	19.1	178.8	1.53

Table F.48
Site B-2 Water Quality Data

Sample Collection Relative to Lead Service Line Replacement	pH	Temp. (deg. C)	Conductivity (umhos/cm)	Total Chlorine (mg/L)
Before	9.5	23.2	176.7	0.24
1 Day After	9.9	22.8	196	1.02
2 Days After	10	22.7	190.5	1.05
3 Days After	9.9	23.7	190.1	0.92
1 Month After	9.8	24.1	165.7	0.79

Table F.49
Site B-3 Water Quality Data

Sample Collection Relative to Lead Service Line Replacement	pH	Temp. (deg. C)	Conductivity (umhos/cm)	Total Chlorine (mg/L)
Before	9.7	20.2	209	0.41
24 hours after	9.9	18.3	178.2	0.41
3 days after	9.6	14.9	280	0.92
1 month after	9.7	20.6	210	0.48
2 months after	9.9	22.8	232	0.39

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.50
Site B4 Water Quality Data

Sample Collection Relative to Lead Service Line Replacement	pH	Temp. (deg. C)	Conductivity (umhos/cm)	Total Chlorine (mg/L)
Before	9.4	17.8	251	1.11
24 hours after	9.3	18.8	207	0.80
3 days after	9.4	19.3	213	0.78
1 month after	9.5	19.3	256	0.79
2 months after	9.3	22.8	230	0.79

Figures F.81 through F.84 display the total and dissolved lead levels measured from flushed samples on the day the lead service was replaced. Site B-1, B-2, and B-4 all experienced high particulate lead levels immediately after the service was replaced.

Lead level results from sequential stagnation samples are displayed in Figures F.85 through F.92. In general, total lead levels were low before replacement activities, with the exception of samples representative of the lead service and the first 125 mL collected at the tap. The majority of lead measured was in the dissolved form before replacement, and again by 1 and 2 months after replacement. For the first three days after replacement however, high particulate lead was measured at several sites.

At Site B-1, the first 125 mL sample, the second liter (representative of the premise piping) and the fifth liter (representative of the lead service) collected exhibited the highest lead levels before replacement. Total lead levels in the first 125 mL sample collected at the tap were very high 1 and 2 days after LSLR, but by one month after LSLR, the total lead levels measured from this sample were below levels measured before replacement. By two months after replacement, lead levels in all samples were below levels measured before replacement. For Site B-2, samples representative of the lead service had the highest lead levels before replacement. Total lead declined immediately in all samples after replacement, and were below 5 ug/L by 1 month after LSLR. Before the replacement, total lead measured from sequential samples at Site B-3 were below 10 ug/L. After replacement, total lead measured in all samples was similar to levels measured before replacement, with the exception of the first 125 mL and 4th liter of sample collected at the tap, which were elevated in all samples for the next three days. At Site B-4, again, lead levels measured from samples representative of the lead service exhibited the highest lead levels. The first 125 ml sample collected at the tap was also relatively high (14 ug/L). After replacement, lead levels were extremely high for up to three days in initial samples collected at the tap, but by 1 month after replacement, lead levels were lower than values measured before LSLR. For three days after replacement, high particulate lead was measured, particularly in the first volumes of water collected at the tap but by one month after LSLR, the majority of lead was again in the dissolved form.

Flushed samples exhibited low lead levels (Figures F.93 through F.96) before replacement at all sites. Higher particulate lead was measured for 1, 2, and 3 days after replacement at several sites.

Calculated first liter lead levels were substantially higher for the first 2 days after replacement at Site B-1, and for the first 3 days for Site B-4. By two months after replacement, calculated first liter total lead levels were below levels measured before replacement *(Note: there is a possibility that the water sampled 2 months after replacement may not have been stagnant for a minimum of 6 hours, as a new tenant had moved into the residence)*. Calculated first liter lead levels at sites B-2 and B-3 were very low, and there was essentially no difference between values measured before or after replacement. (Figure F.97 through F.100)

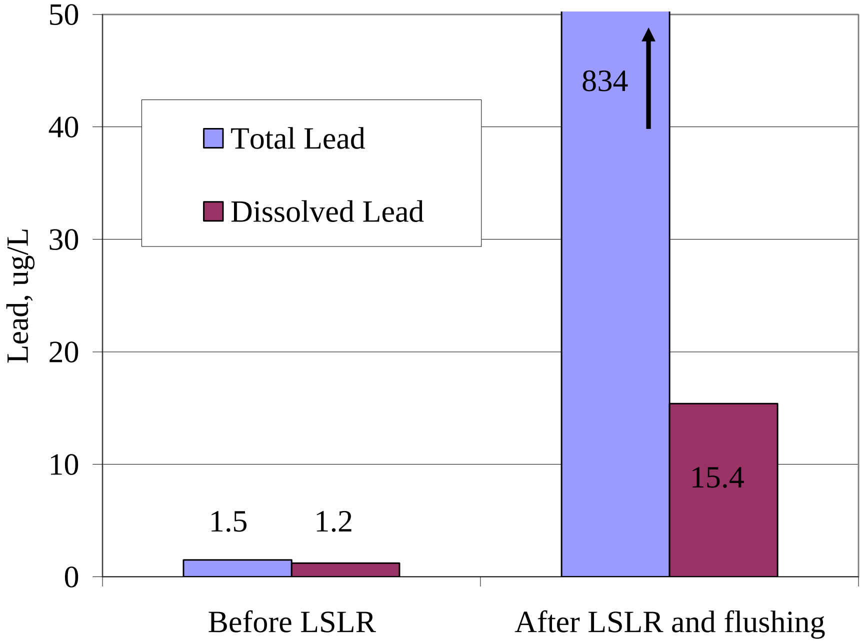


Figure F.81 Lead Levels Measured the Day of Replacement at Site B-1 (flushed)

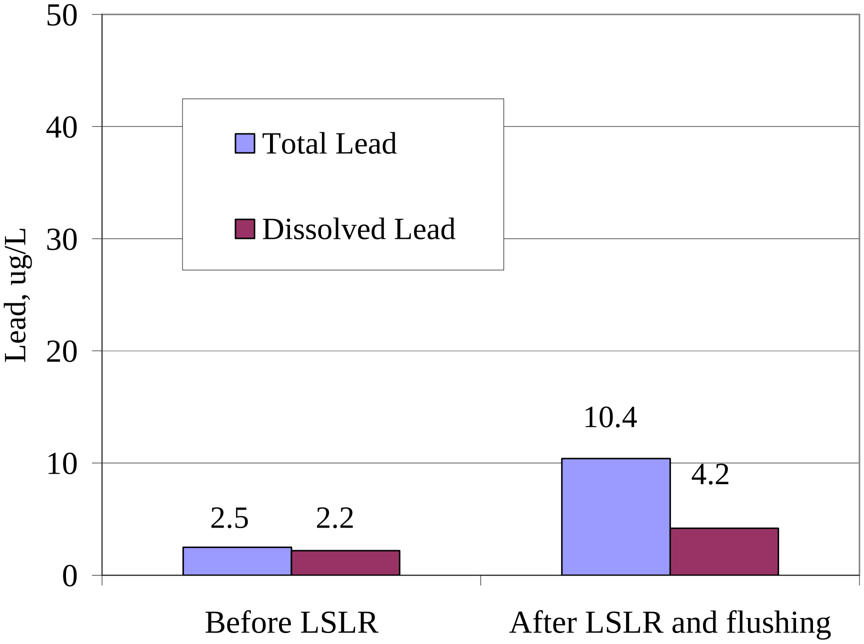


Figure F.82 Lead Levels Measured the Day of Replacement at Site B-2 (flushed)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

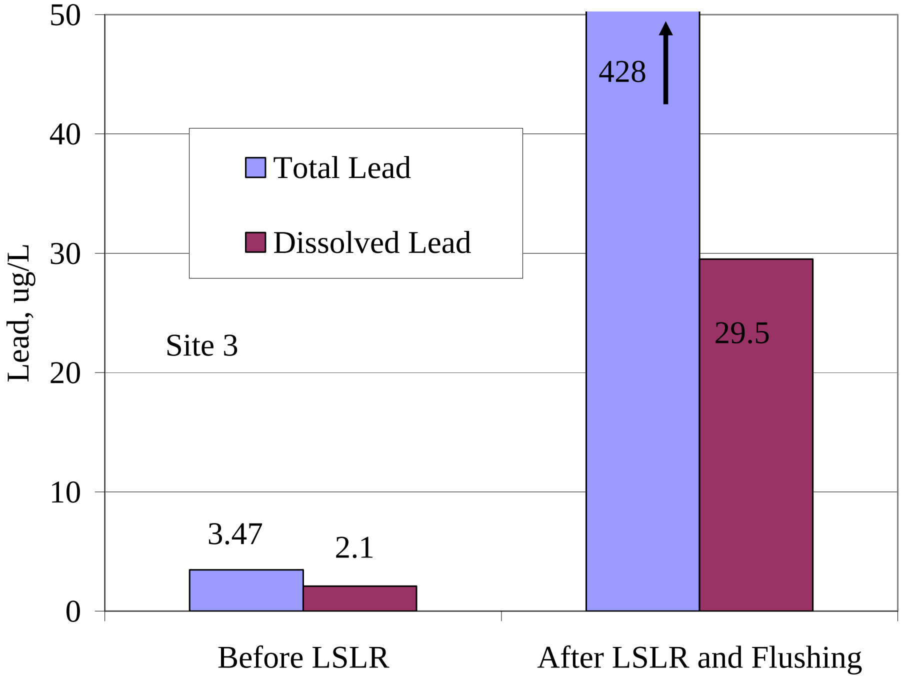


Figure F.83 Lead Levels Measured the Day of Replacement at Site B-3 (flushed)

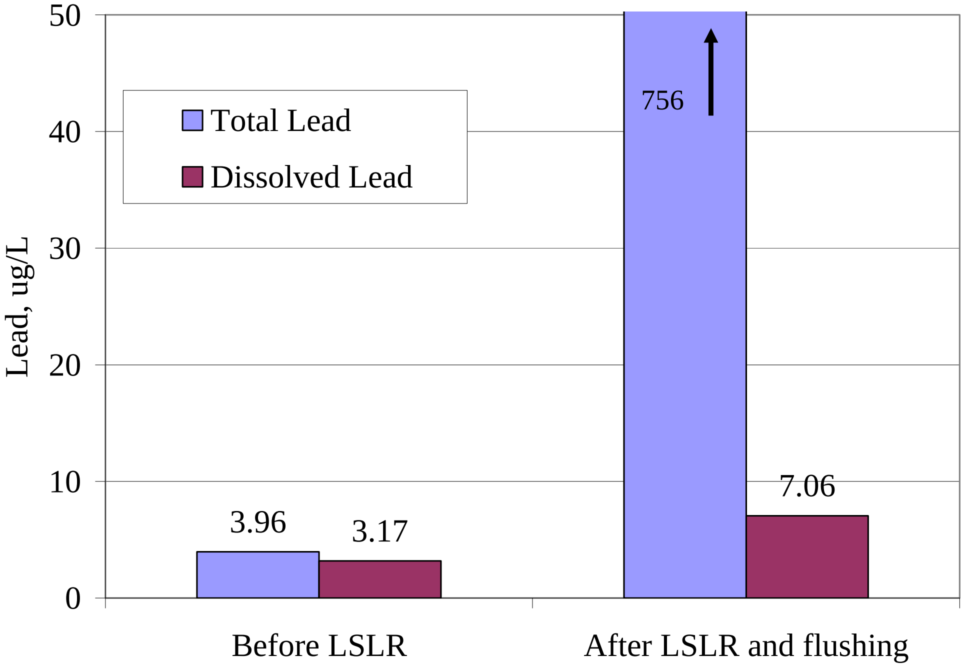


Figure F.84 Lead Levels Measured the Day of Replacement at Site B-4 (flushed)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

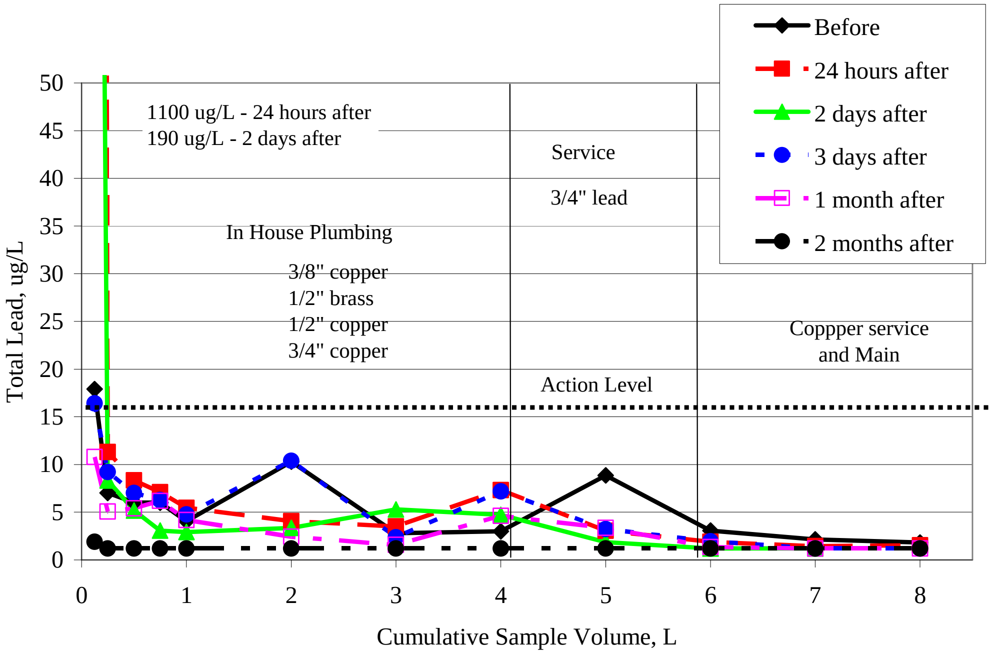


Figure F.85 Site B-1 Total Lead Level Concentration Profiles (stagnation)

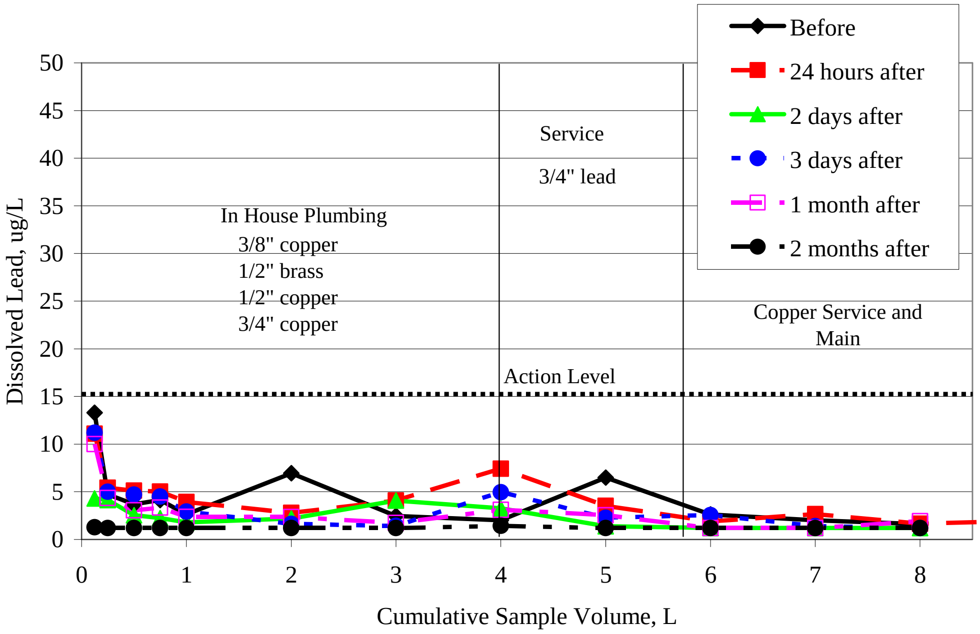


Figure F.86 Site B-1 Dissolved Lead Level Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

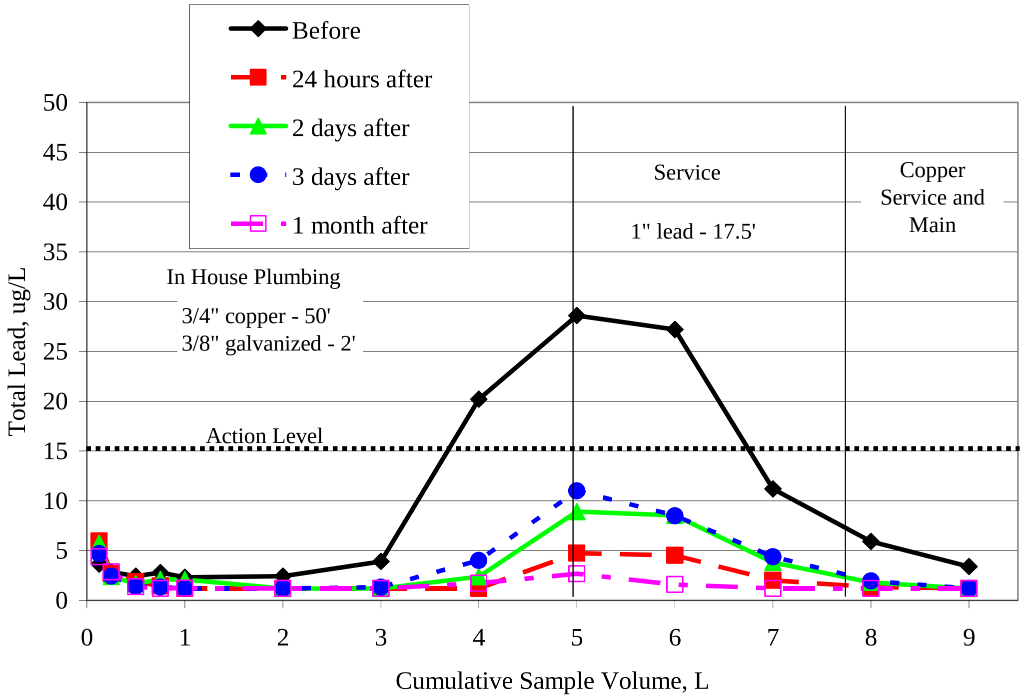


Figure F.87 Site B-2 Total Lead Level Concentration Profiles (stagnation)

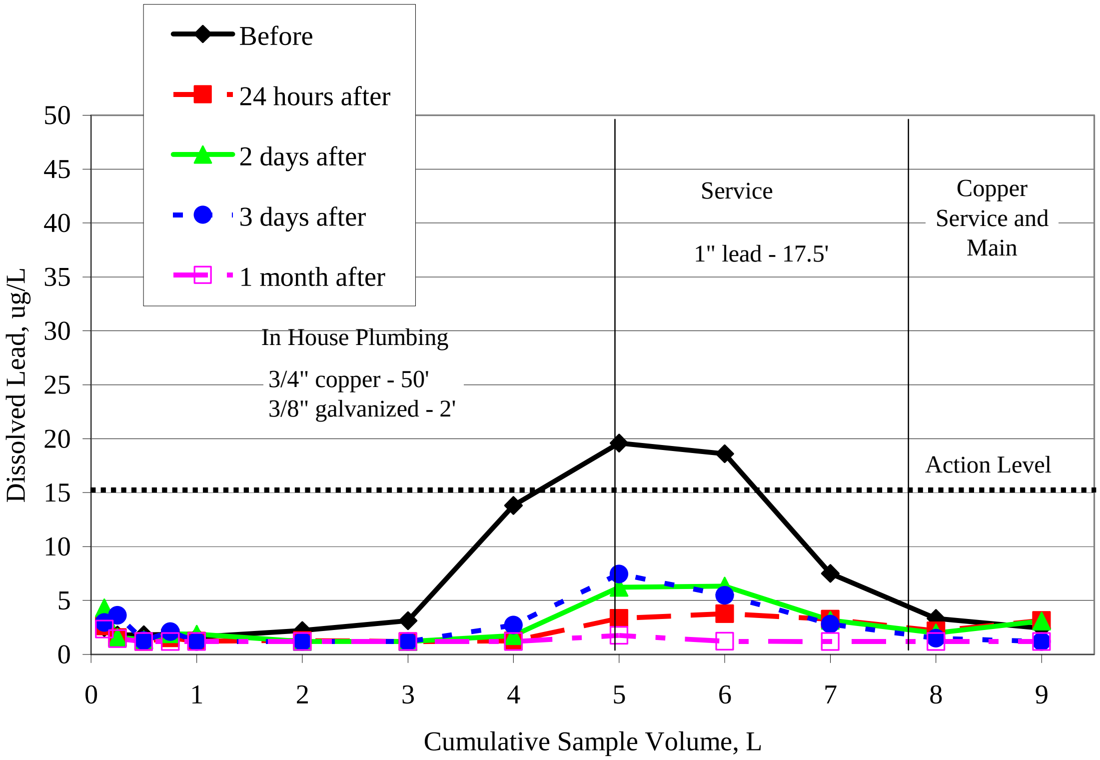


Figure F.88 Site B-2 Dissolved Lead Level Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

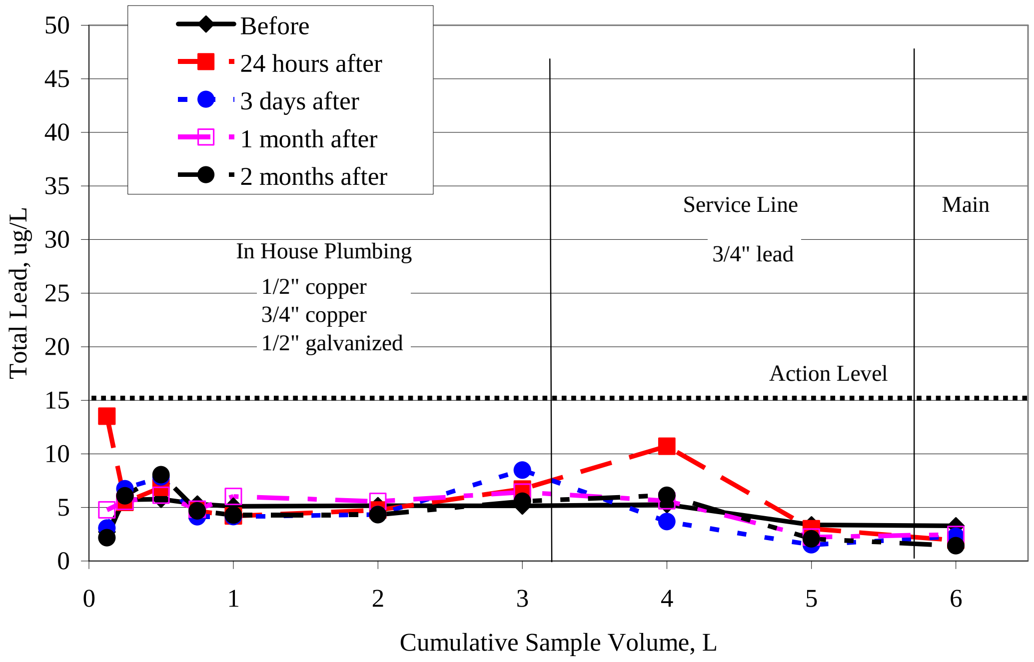


Figure F.89 Site B-3 Total Lead Level Concentration Profiles (stagnation)

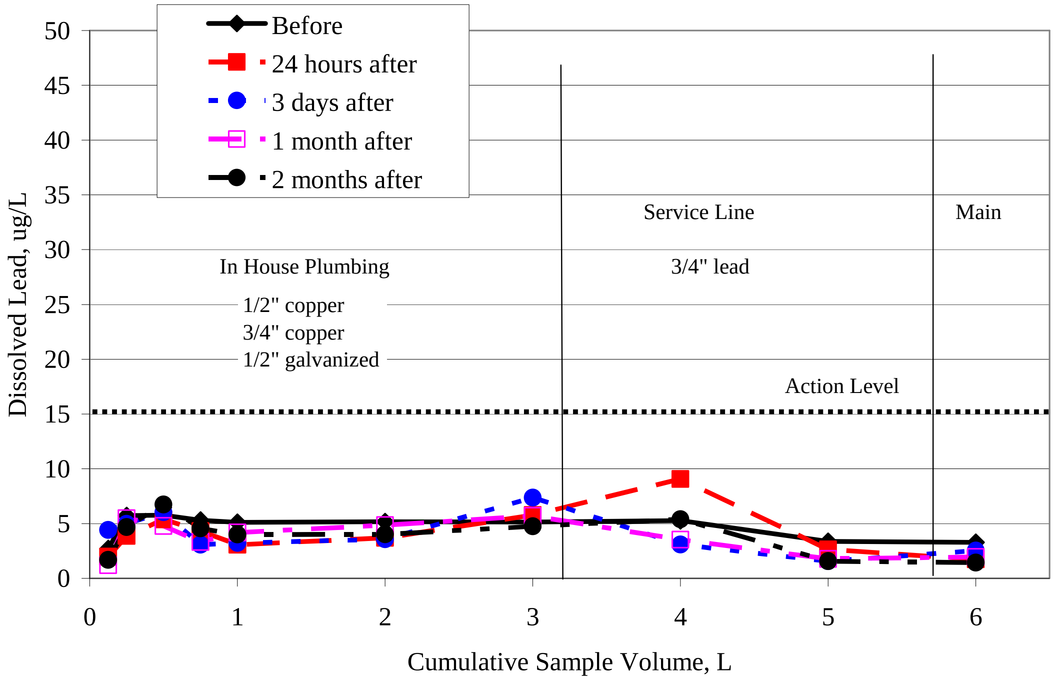


Figure F.90 Site B-3 Dissolved Lead Level Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

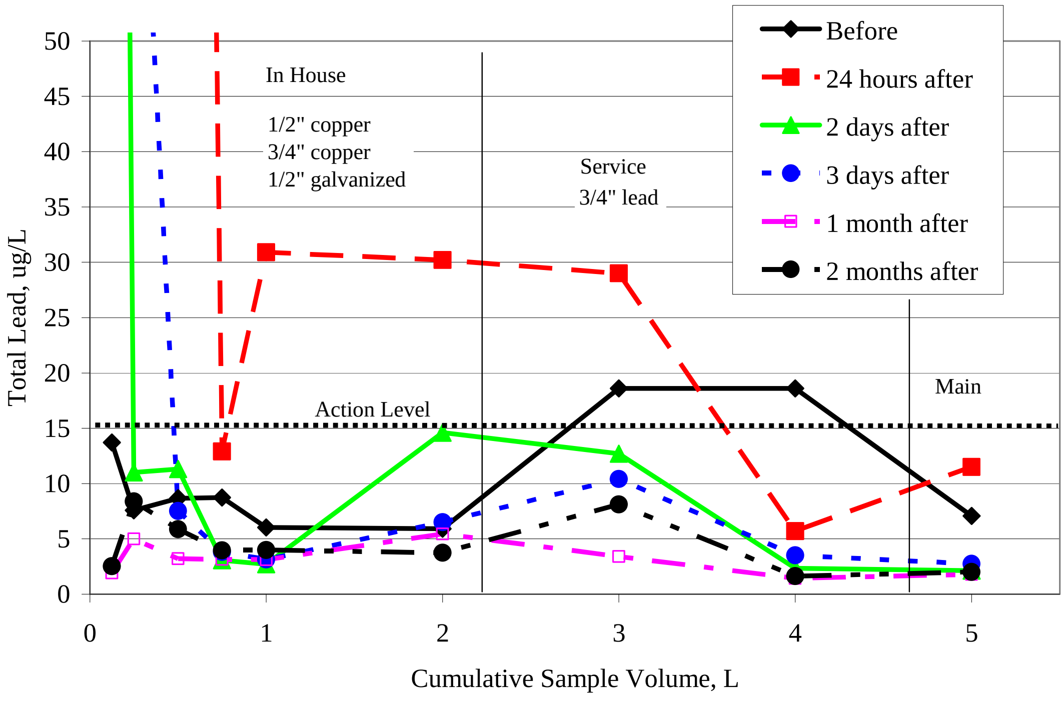


Figure F.91 Site B-4 Total Lead Level Concentration Profiles (stagnation)

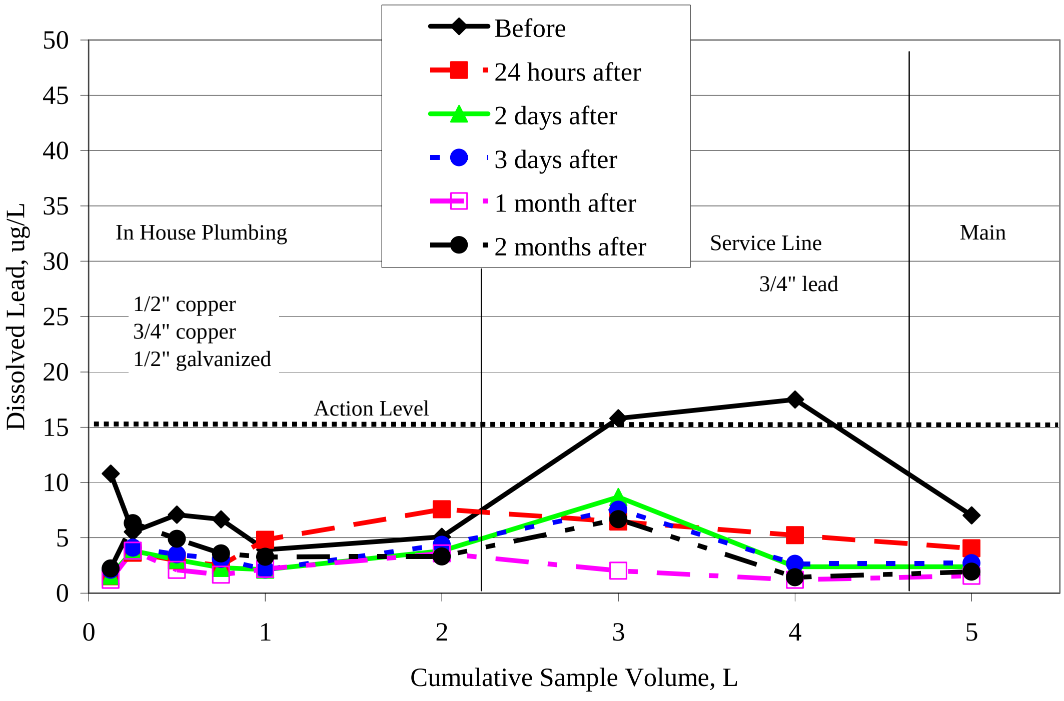


Figure F.92 Site B-4 Dissolved Lead Level Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

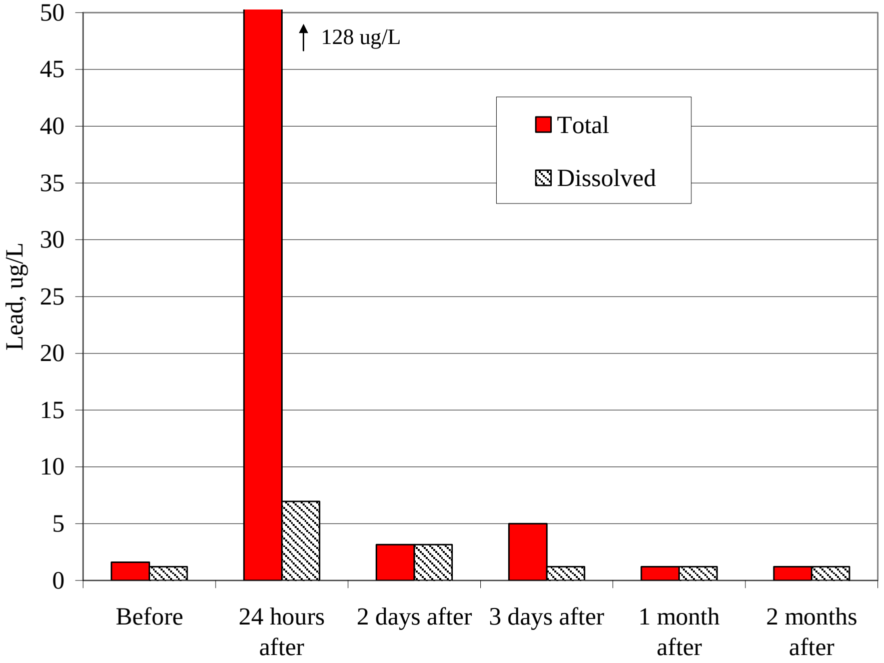


Figure F.93 Total and Dissolved Lead from Flushed Samples at Site B-1

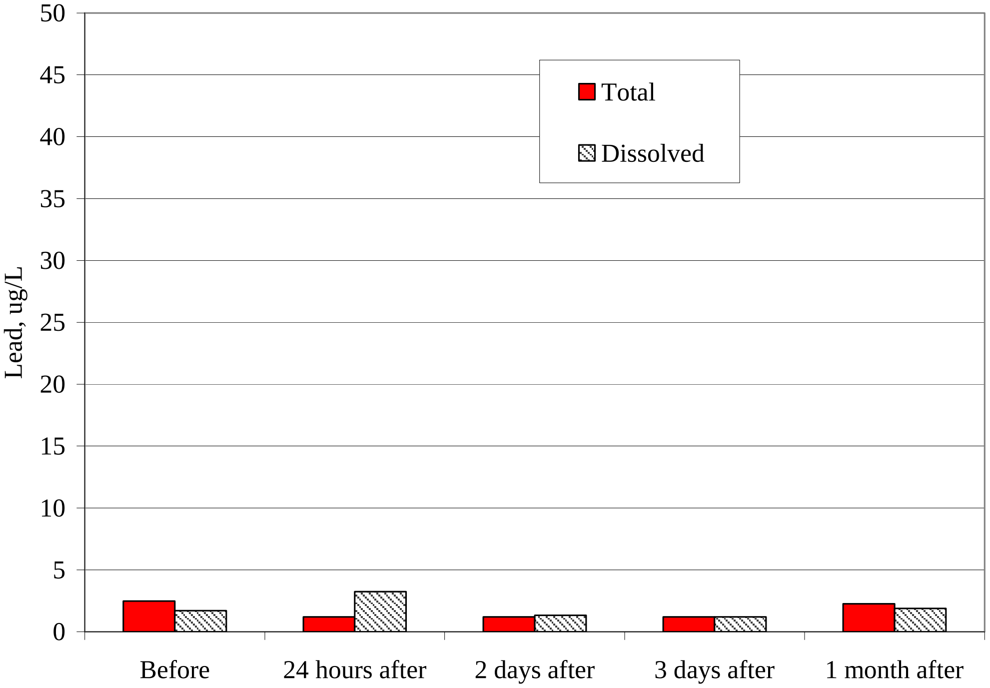


Figure F.94 Total and Dissolved Lead from Flushed Samples at Site B-2

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

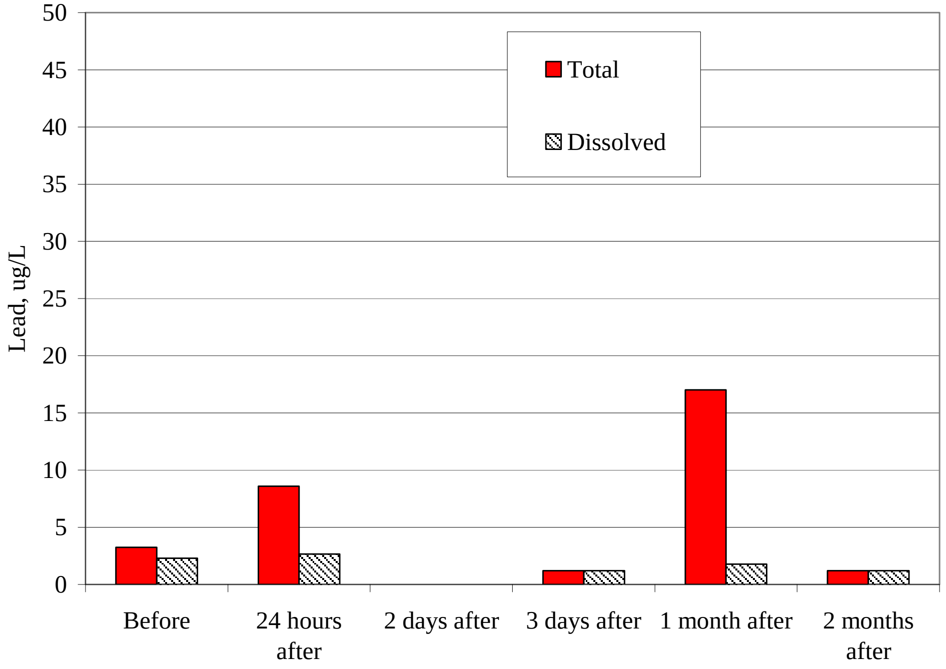


Figure F.95 Total and Dissolved Lead from Flushed Samples at Site B-3

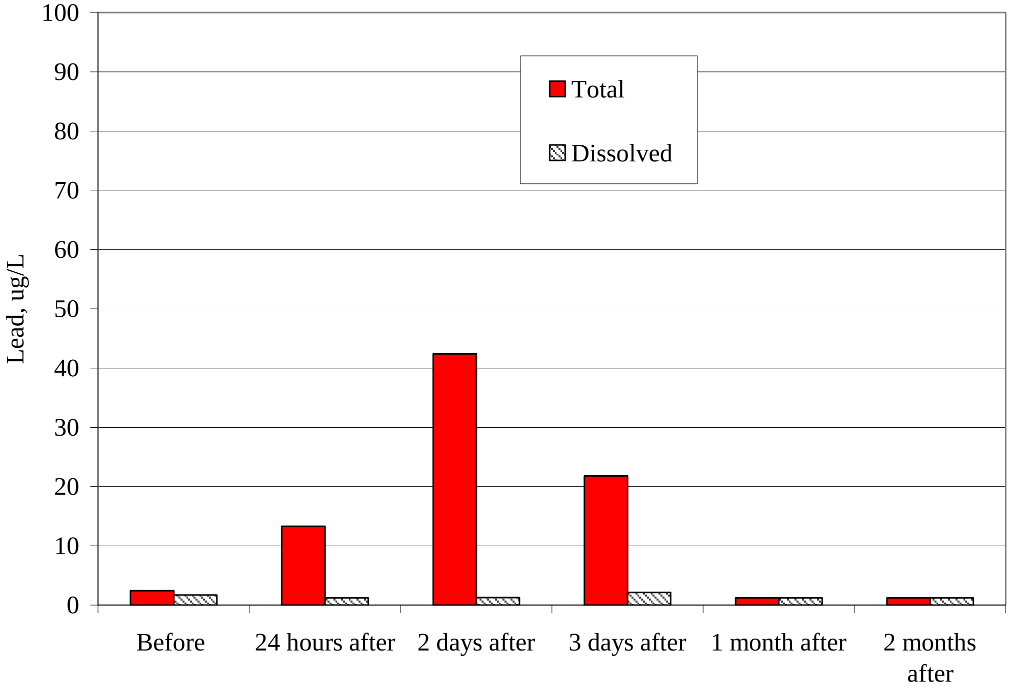


Figure F.96 Total and Dissolved Lead from Flushed Samples at Site B-4

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

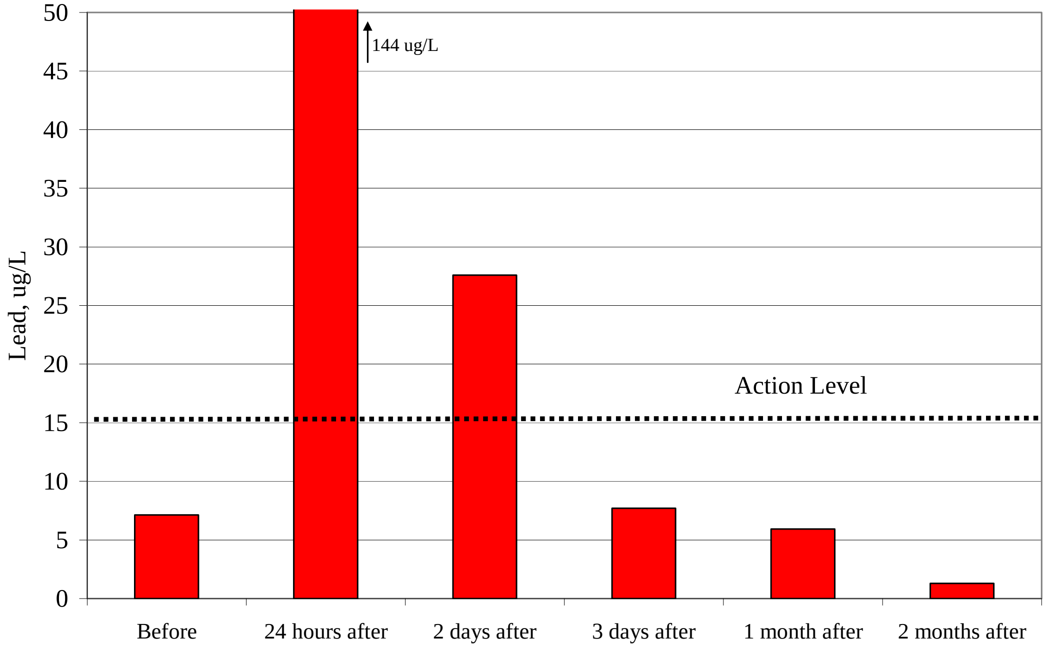


Figure F.97 Calculated First Liter Lead Level Results at Site B-1 (stagnation samples)

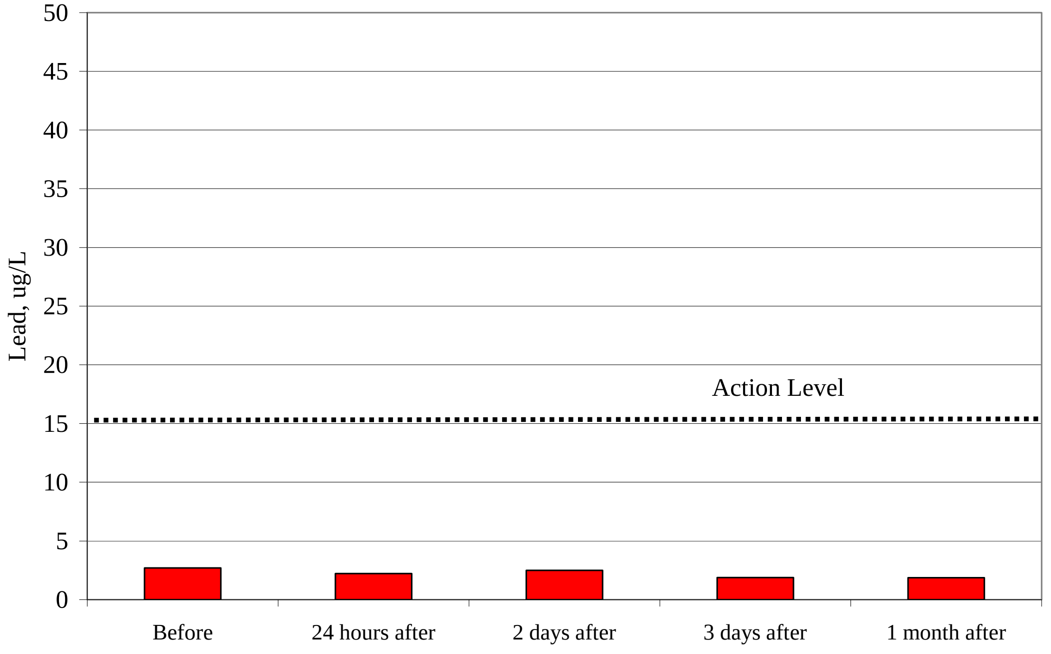


Figure F.98 Calculated First Liter Lead Level Results at Site B-2 (stagnation samples)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

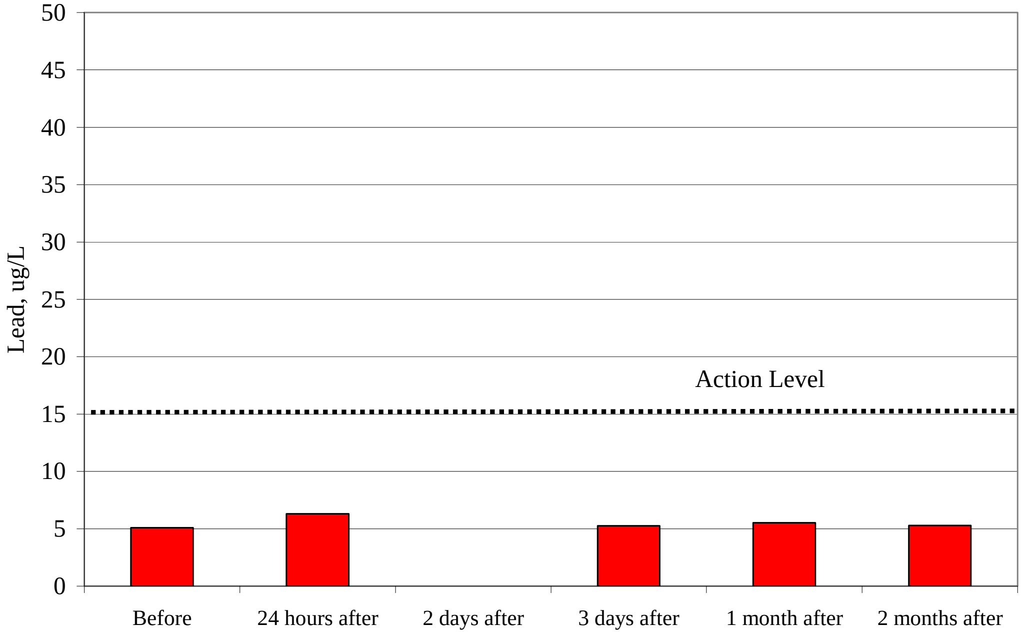


Figure F.99 Calculated First Liter Lead Level Results at Site B-3 (stagnation samples)

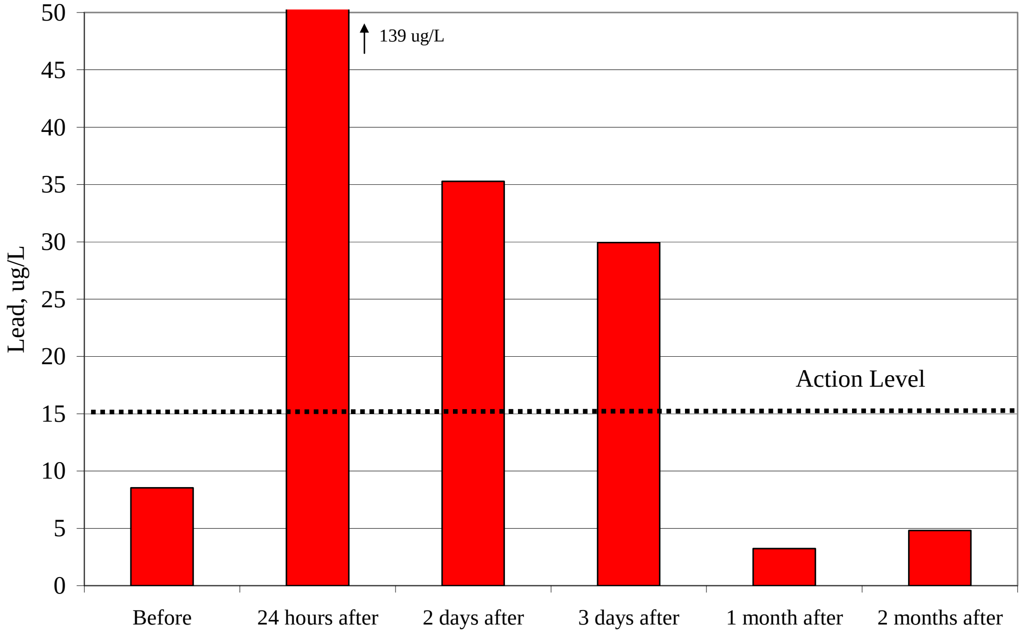


Figure F.100 Calculated First Liter Lead Level Results at Site B-4 (stagnation samples)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scale Analysis. Pipe samples received from Boston, which included a lead service line and brass premise piping, are listed in Table F.51 along with the laboratory numbers assigned to each section of these pipes. Lead service piping was unable to be extracted from Sites B-1 through B-4 because of site constraints, so a lead service piping section was extracted from an additional site (Site B-5) that was used for a pipe cutting evaluation (discussed later in this appendix).

Table F.51
Plumbing Specimens Received from BWSC for Scale Analyses

Street address	Laboratory number	Description
B-1	03_PB01	Brass pipe, premise piping
B-1	03_PB02	Brass pipe, premise piping
B-5	03_PP03	Lead pipe, service branch
B-5	03_PP04	Lead pipe, service branch

Scales were scraped from these pipes and analyzed by x-ray diffraction, x-ray fluorescence, Raman spectroscopy, and SEM-EDS for mineralogy and chemistry. These results were then compared to water chemistry.

Water chemistry. As discussed previously, the BWSC receives water from the Massachusetts Water Resources Authority (MWRA), which uses surface water stored in the Quabbin and Wachusett Reservoirs west of the city. Table F.52 lists a summary of both the distributed water quality for MWRA in 2006 and the water quality results from flushed samples collected before the lead service was replaced at Site B-1.

Scale properties. Pipe samples received from site B-1 were brass, from interior plumbing, whereas the pipes from site B-5 were from a lead service line. As expected, the brass pipe scales were dominated by copper minerals and the lead pipe scales were dominated by lead minerals (Table F.53). The brass pipes had appreciable Zn, Ca, Fe, and Si in addition to Cu, and also had small amounts of Al, Mn and P. Barium occurred in the surface scale of pipe 03_PB01 from site B-1. Layer 1 scales (the layer closest to the water) had larger amounts of these other elements, particularly Fe, whereas Layer 2 was mostly Cu. The lead samples (Site B-5) were dominated by Pb, with high Ca, Fe, and Mn in Layer 1. Phosphorus (P) was low and vanadium (V) was very low in scales on both lead and brass.

Table F.52
Water Quality Parameters for Distributed Water and Site B-1 Before Replacement

Parameter	units	Distribution Water Quality for August 2006*	Site B-1
pH	pH Units	9.4	9.80
Sulfate	mg/l	7.90	6.64
Calcium	mg/l	5.81	4.83
Magnesium	mg/l	1.05	0.86
Potassium	mg/l	1.08	0.97
Sodium	mg/l	31.8	28.20
Silica	mg/l as SiO_2	4.19	2.74
Aluminum	µg/l	28.3	<15.00
Iron	µg/l	53.30	43.10

**from MWRA water quality report. Parameters below detection included As, Cr, Ni, Pb, Se*

Site B-1. Visually, the brass pipes from site B-1 showed several colors and textures (Figure F.101). There was a greenish, weakly adhering scale, possibly malachite or brochantite. More tightly adhering scales were dark and light brown, likely tenorite and cuprite. Occasional spots of white material were present but were not common. X-ray diffraction patterns showed the two copper oxide minerals tenorite, CuO and cuprite, Cu_2O. Tenorite dominated in pipe 03_PB01, whereas cuprite dominated in 03_PB02 (Figure F.102). It is likely that PB01 may have been the hot water line and PB02 the cold water line. Layer 1 in each pipe was less crystalline than layer 2.

Table F.53
Bulk Chemical Composition of Scales from Boston MWRA Service Line Replacement Sites (values in weight %)

Sample	Site	Material	Pb	Zn	Cu	Al	Ba	Ca	Fe	Mn	P	S	Si	V
03PB01A1L1	B1	Brass	0.59	3.28	45.6	0.26	0.109	13.5	4.44	0.46	0.18	0.01	1.09	0.011
03PB01A1L2	B1	Brass	0.15	3.16	72.0	0.36	0.055	8.00	1.74	0.09	0.07	0.00	0.67	0.000
03PB02A1L1	B1	Brass	0.81	5.47	27.3	0.40	0.029	6.42	10.9	0.30	0.35	0.02	1.07	0.006
03PB02A1L2	B1	Brass	0.11	2.95	65.8	0.00	0.002	7.88	1.63	0.07	0.84	0.00	0.31	0.003
03PP04A1L1	B5	Lead	37.2	0.021	0.11	0.43	0.000	3.96	2.45	1.31	0.08	0.82	1.00	0.025
03PP04A1L2	B5	Lead	71.7	0.004	0.04	0.09	0.067	1.71	0.45	0.25	0.03	1.20	0.11	0.007
Average scale on brass			0.41	3.71	52.7	0.26	0.049	8.96	4.68	0.23	0.36	0.01	0.78	0.005
Average scale on lead			54.4	0.012	0.07	0.26	0.033	2.83	1.45	0.78	0.06	1.01	0.56	0.016

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

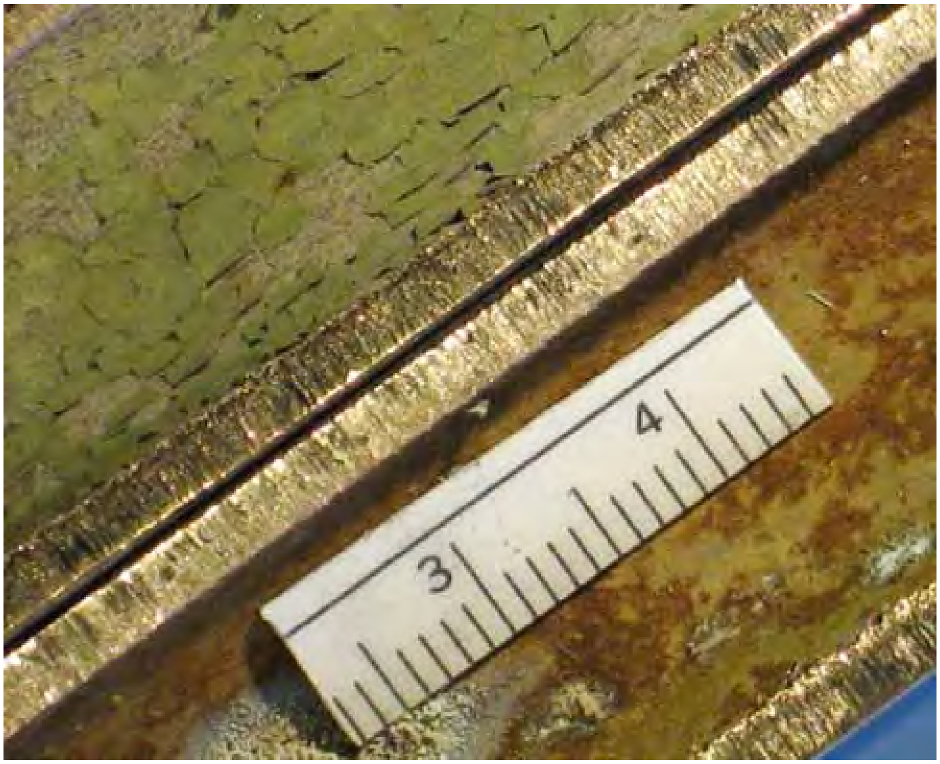


Figure F.101 Photograph of the Surface of Scale from Pipe PB01 (top) and PB02 (bottom) from Site B1.

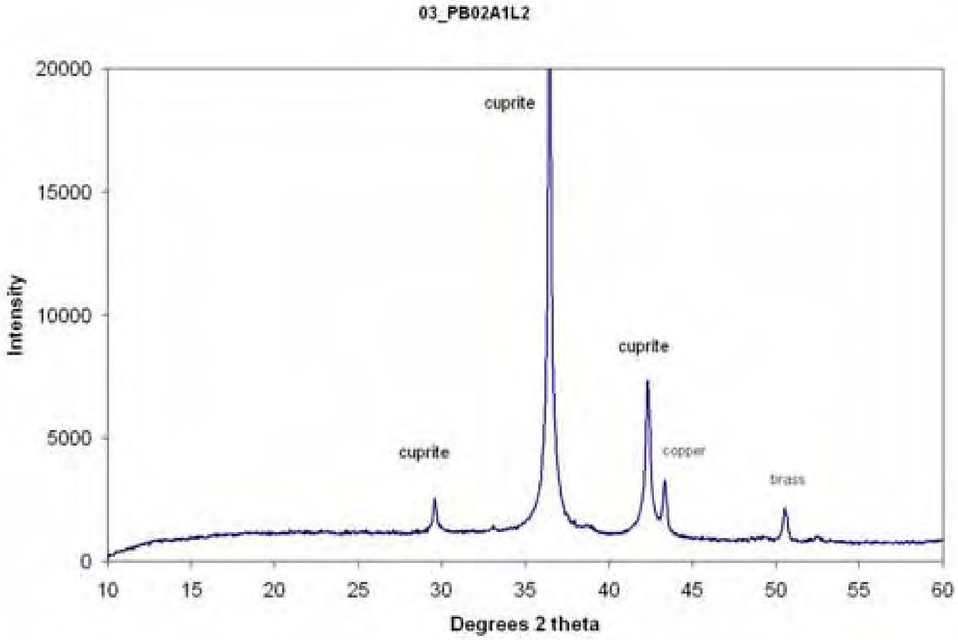


Figure F.102 Typical X-ray Diffraction Pattern for Site B1 Scales. The only crystalline scale phase is cuprite (Cu_2O).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Raman spectroscopy revealed the presence of small amounts of barite ($BaSO_4$) in the surface layer of PB01 (Figure F.103). This phase is seldom reported from corrosion scales, but should in fact be common based on equilibrium models of water chemistry. It should also be noted that Ba was found at a level of 1000 ppm in the XRF analysis of this sample.

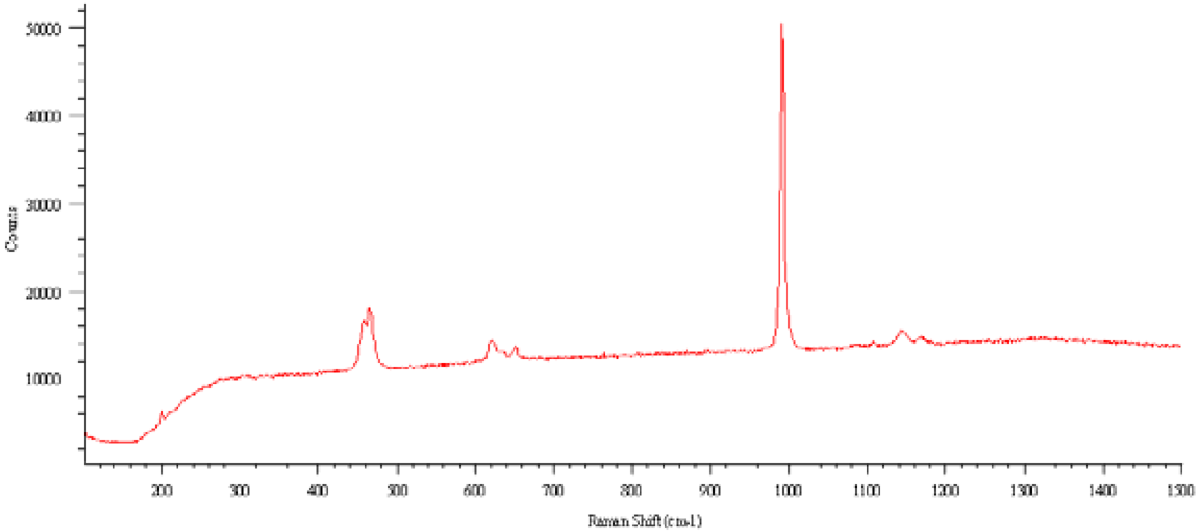
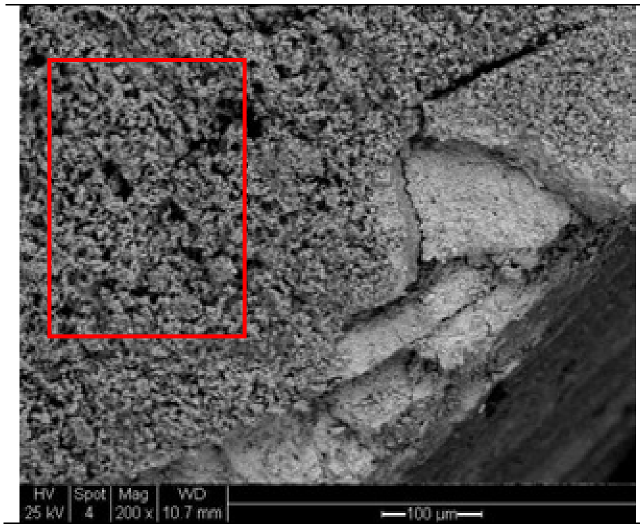


Figure F.103 Raman Scattering Spectrum for 03_PB01 Layer1. The peaks at 456.9, 465, 620, 650.7, 991, 1145, 1170 cm^{-1} are typical of barite.

In SEM imaging, the scale was texturally simple and chemically homogeneous (Figure F.104). The Zn/Cu ratio of the scale was higher than in the underlying brass pipe, reflecting selective dissolution of Zn from the brass ("dezincification"), but showing significant retention of the released Zn in the scale.



Element	*Wt%*	*At%*
C	5.91	20.2
O	9.27	23.8
Al	0.37	0.56
Si	0.79	1.15
Ca	0.34	0.34
Fe	1.19	0.88
Cu	78.2	50.6
Zn	3.97	2.49

Figure F.104 SEM image and Corresponding EDS Analysis of Copper Oxide Scale Overlying Brass. The Zn/Cu ratio of the brass is 0.038, whereas in the scale it is 0.051. The XRF results give Zn/Cu average of 0.07. The C in the EDS results is a high blank resulting from the use of carbon mounting tape.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Site B5. Pipe samples from site B-5 were from lead service piping. As shown in Figure F.105, sample PP04 had two layers. At the surface was a rough outer layer with mixed orange-brown and dark brown patches. Beneath this material was a smooth, even white scale. Based on XRD (Figure F.106), XRF and Raman determinations, the dark brown surface material in the surface scale is plattnerite [PbO_2] and the orange-brown material is Fe oxide with lesser amounts of Mn oxide. The underlying white material is the Pb carbonate hydrocerussite [$Pb_3(CO_3)_2(OH)_2$]. SEM-EDS analysis of the scales from site B5 shows the presence of interlocking hexagonal plates of hydrocerussite (Figure F.107 and F.108).

Figure F.105 Photograph of Pipe PP04 from Site B5.

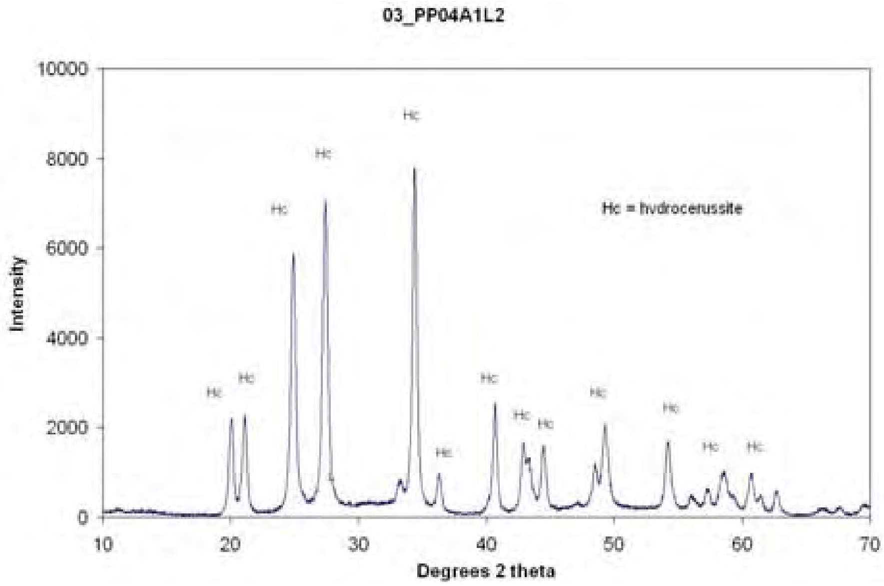
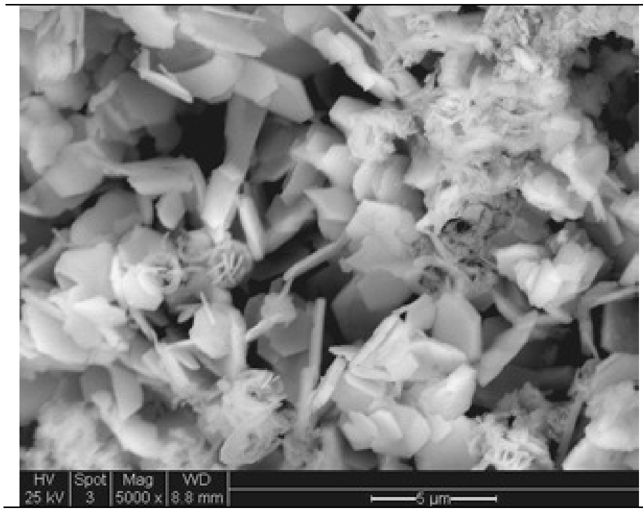


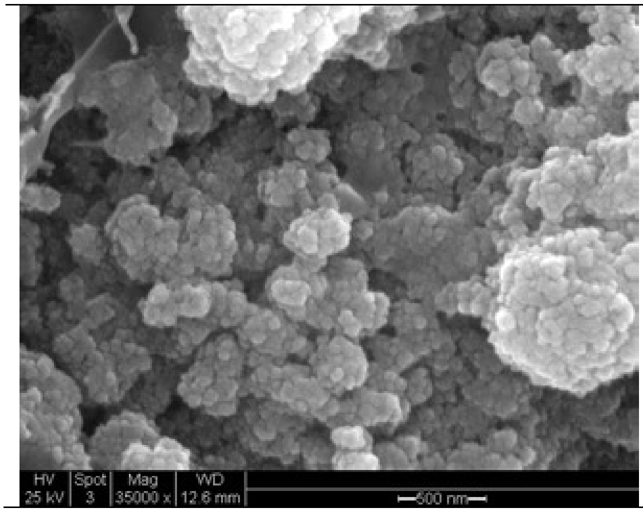
Figure F.106 Typical X-ray Diffraction Pattern for Site B5 Scales. The only crystalline scale phase in Layer 2 is hydrocerussite. Layer 1 patterns also show some plattnerite.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.



Element	*Wt%*	*At%*
C	7.04	40.9
O	6.86	29.9
Pb	86.1	29.1

Figure F.107 SEM Analysis of Sample PP03. The image is in backscattered mode and shows even brightness, which indicates a homogeneous Pb distribution. No metallic elements other than Pb were detected. Note that there is a high C blank that distorts the ratio of Pb to the light elements.



Element	*Wt%*	*At%*
C	11.8	38.8
O	12.5	31.0
Si	2.90	4.14
Ca	0.71	0.70
Mn	1.70	1.22
Fe	20.8	14.6
Pb	49.4	9.41

Figure F.108 SEM Analysis of Sample PP03. The image is in scanning mode at high magnification and shows fine-grained, amorphous Fe oxide. A small amount of Mn is present at Mn/Fe = 0.083. Mn/Fe in the bulk scale is higher, at about 0.5, so other areas rich in Mn are likely present.

PHREEQC modeling. A speciation-saturation state model was constructed for the water compositions measured at each site, supplemented with data from the treatment plant (Table F.54). The oxidation state was set at the upper stability limit for water, based on the presence of free chlorine at each site. This procedure underestimates the oxidation state of the system somewhat, but is the maximum allowed by the model. The mineral most affected is plattnerite, which is probably more stable than shown.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.54
Saturation index (SI) for likely scale minerals in the Boston water distribution system

Mineral	Formula	Site B-1
Supesaturated		
Hydroxylapatite	$Ca_5(PO_4)_3OH$	5.41
Goethite	FeOOH	4.94
Manganite	MnOOH	3.39
Malachite	Cu2(OH)2CO3	2.64
Tenorite	CuO	2.47
Ferrihydrite	Fe(OH)3	2.20
Brochantite	Cu4(OH)6SO4	1.57
Saturated		
Azurite	Cu3(OH)2(CO3)2	0.46
Calcite	CaCO3	0.43
Plattnerite	PbO2	0.39
Zincite	ZnO	-0.23
Langite	Cu4(OH)6SO4:H2O	-0.58
Undersaturated		
Barite	BaSO4	-1.39
Cerussite	PbCO3	-1.87
Smithsonite	ZnCO3	-2.21
Pyromorphite-Cl	Pb5(PO4)3Cl	-2.75
Hydrocerussite	Pb3(OH)2(CO3)2	-2.90
Litharge	PbO	-4.42
Cuprite	Cu2O	-15.48

A variety of Cu, Fe, and Mn oxides were supersaturated in the water from site B-1. Of the possible Pb minerals, only plattnerite was supersaturated, which is consistent with its appearance in the surface scale layer at site B5, but there is insufficient water chemistry data to effectively evaluate that site.

FAUCET REPLACEMENT

Existing residential faucets were replaced at single family homes located in Framingham, MA and Hartford, CT. Framingham, MA is a retail water systems served by the MWRA, while Hartford, CT is served by the Metropolitan District Commission (MDC). Framingham receives water from the MWRA, which adjusts alkalinity and pH for corrosion control (pH ~9.7) and uses ozone and chloramines for disinfection. Typical finished water quality for the MWRA is listed in Table F.45. The MDC Hartford utilizes slow sand and rapid sand filtration processes to treat its surface water. Average finished water pH is ~ 7.6 and orthophosphate is used for corrosion control (typical finished water level of 0.9 mg/L as P). The following section describes the overall site selection process, sampling protocol, and results obtained.

Site Selection and Sampling Protocols

At each location, residential sites were selected according to the following criteria:

- Site does not have any home water treatment systems (i.e. water softener, home reverse osmosis units, kitchen tap filter, etc.)
- Site is located in part of the distribution system where the water quality (especially chlorine and alkalinity) does not vary significantly over time or where the chlorine residual is routinely absent.
- Site is not located along a dead-end water main.
- Site does not have double service lines or is served by a service line header.
- The site service line or premise plumbing does not have any water leaks.
- Homeowner agrees not to use water during the daytime stagnation period.

A premise piping survey was conducted at each site prior to sampling to determine the length and diameter of pipe between the kitchen faucet and the main. Table F.55 lists the material, diameter, length, and volume of water contained in each section of piping from the three sites.

At Site F.1, the site survey indicated a service line of both lead and copper, with copper premise piping. The site survey for Site F.2 indicated a lead service line with copper premise piping. At Site MDC-1, both the premise and service piping were copper. This site was selected because an inspection in 2001 had indicated excessive use of flux in the interior piping. At all sites, the original faucets were replaced with a Chicago 2300-8CP faucets (Figure F.109) manufactured with Envirobrass, a non-leaded alloy.

Water samples were collected at the kitchen tap before and after faucet replacement (1, 2, 3, and 4 weeks after). At Framingham, sampling consisted of an initial flushed sample (15 minutes +), followed by a series of sequential samples collected after the water was allowed to stagnate for a minimum of 6 hours. At the MDC site, a series of sequential samples were collected after a minimum 6 hour stagnation period, followed by the collection of a flushed sample. Stagnation samples collected were 125mL and 250mL in volume, followed by one liter samples. The number of samples collected was calculated based on the site survey information. Table F.56 lists the samples collected. Total and dissolved lead were analyzed on all samples, with filtration of samples occurring in the field, or shortly thereafter. The kitchen faucet remained open for the entire sampling duration, as opposed to opening and closing the faucet between samples. For all samples, any aerator on the kitchen faucet remained attached during sampling. Field temperature, pH, conductivity or TDS, total and free chlorine measurements were taken during each sampling event. In addition, at some utility locations, alkalinity and major cation/anions were measured on selected samples.

Figure F.109 Replacement Faucet 2300-8CP (without sprayer)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.55
Site Survey Information for Faucet Replacement Evaluations

Site No.	Location	Piping	Pipe Length, feet	Volume, L
F.1	Kitchen faucet to service line entry to house	1/2" copper 3/4" copper	19.8 33.0	0.91 3.14
	Service	5/8" lead 1" copper	29.5 7.5	1.84 1.22
	Total			**7.10**
F.2	Kitchen faucet to service line entry to house	1/2" copper	64.0	2.94
	Service	5/8" lead	94.2	5.88
	Total			**8.82**
MDC-1	Kitchen faucet to service line entry to house	1/2"copper 3/4" copper	5.0 44.0	0.23 4.18
	Service	1" copper	70.4	11.40
	Total			**15.80**

Table F.56
Samples Collected for Faucet Replacement Study

Sample No.	Volume	Conditions	Before Faucet Replacement	1, 2, 3, and 4 weeks after Faucet Replacement
1	1 L	Flushed, before stagnation	X	X
2	125 mL	After stagnation	X	X
3	125 mL	After stagnation	X	X
4	250 mL	After stagnation	X	X
5	250 mL	After stagnation	X	X
6	250 mL	After stagnation	X	X
7- 15	1 L	After stagnation	X	

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Results

Water Quality. Chlorine concentration, pH, temperature, and conductivity were performed on-site during sample collection. Results are displayed in Tables F.57 through F.59. Results were consistent between sites in Framingham, with the exception of temperature and total chlorine residual which fluctuated during the course of the sampling.

Table F.57
Site F.1 Water Quality

		pH	Temperature, °C	Total Cl_2, mg/L	Free Cl_2, mg/L	Conductivity, umhos/cm
Before	flushed	-	-	-	-	-
1 week	flushed	-	17.1	1.84	0.07	-
2 weeks	flushed	9.5	16.2	2.10	0.50	201
3 weeks	flushed	-	-	-	-	-
4 weeks	flushed	9.5	14.7	1.98	0.11	185
Before	stagnation	9.7	21.9	0.02	0.05	228
1 week	stagnation	9.7	17.4	1.35	0.03	-
2 weeks	stagnation					
3 weeks	Stagnation	-	-	-	-	-
4 weeks	stagnation	9.5	16.8	1.29	0.04	233

Table F.58
Site F.2 Water Quality

		pH	Temperature, °C	Total Cl_2, mg/L	Free Cl_2, mg/L	Conductivity, umhos/cm
Before	flushed	-	-	-	-	-
1 week	flushed	9.6	21.3	1.56	0.10	-
2 weeks	flushed	9.5	17.6	1.92	0.40	204
3 weeks	flushed	-	-	-	-	-
4 weeks	flushed	9.4	20.7	1.79	0.05	189
Before	stagnation	9.4	22.4	0.23	0.04	334
1 week	stagnation	9.6	18.8	0.63	0.00	-
2 weeks	stagnation					
3 weeks	stagnation	9.3	21.7	0.89	0.60	231
4 weeks	stagnation	9.3	20.3	0.8	0.06	228

Table F.59
Site MDC-1 Water Quality

		pH	Temperature, °C	Conductivity, umhos/cm	Total Cl_2, mg/L	Free Cl_2, mg/L	ORP
Before	flushed	7.7	15.9	84	0.15	0.15	468
Before	stagnation	7.5	18.9	88	0.05	0.00	385
1 week	stagnation	7.8	18	72	0.10	0.04	-
2 weeks	stagnation	7.4	16.6	60	0.10	0.05	-
3 weeks	stagnation	7.6	14.7	58	0.01	0.00	-
4 weeks	stagnation	7.7	14	64	0.03	0.01	-

Lead Levels. Lead level results are displayed in Figures F.110 through F.121. At Site F.1 (partial lead service line), initial 125 and 250 mL sample volumes all exhibited total lead levels below the action level of 15 ug/L prior to faucet replacement, however, the impact of the lead service line is clearly indicated by the elevated lead levels measured from samples collected from the 5th, 6th, and 7th liters of water collected at the tap. One week after faucet replacement, total lead levels were elevated, but declined over time. The lead level in the initial 125 mL sample collected at the tap before faucet replacement was lower than the initial 125 mL samples collected after replacement. The original older faucet had likely leached most of the lead, and it was presumed that the replacement Chicago faucet (manufactured with Envirobrass) would not contribute to lead in this initial sample (although this was not found to be the case in the faucet pilot test conducted for this project at the Portland Water Bureau). Physical disturbance of the premise piping during the faucet replacement procedure and/or continued contributions from the existing lead service line could be the sources of lead in samples taken after faucet replacement.

At Site F.2 (full lead service), all sample volumes exhibited total lead levels above the action level of 15 ug/L prior to faucet replacement. Two lead peaks were evident, one associated with the premise piping and one associated with the lead service line. Total lead levels in the initial two 125 mL samples were higher after faucet replacement in all samples collected (i.e. at 1,2,3, and 4 weeks after faucet replacement), when compared to the initial 125 mL samples collected before replacement. Sequential samples collected 1,2,3, and 4 weeks after replacement also all exhibited total lead levels above the action levels of 15 ug/L but were generally lower than samples collected before replacement (with the exception of the initial two 125 mL samples collected at the tap). Again, physical disturbance of the premise piping during the faucet replacement procedure and/or continued contributions from the existing lead service line could be the sources of lead in samples taken after faucet replacement.

Site MDC- 1 (no lead service) was inspected in 2001 and excessive use of flux was noted in the interior piping. Since there are no lead service lines in the MDC service area, the source of lead measured at the tap is likely the faucet, solder from premise piping, and/or other lead containing fittings in premise and distribution system piping. Initial 125 and 250 mL sample volumes all exhibited very low lead levels, with non-detectable lead measured in all samples with the exception of the initial two 125 mL samples collected at the tap. One week after faucet replacement, total lead levels were elevated over background levels in all samples but were still below the action level of 15 ug/L. Total and dissolved lead levels measured from sequential stagnation samples indicate that the majority of lead is in the dissolved form.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Total and dissolved lead levels measured from flushed samples at Framingham are displayed in Figures F.122 and F.123. At Site F.1, levels between 3 – 9 ug/L were measured in fully flushed samples and more particulate lead was measured in flushed samples taken 1 and 2 weeks after replacement when compared to samples collected before replacement and 3 and 4 weeks after replacement. For Site F.2, fully flushed samples collected at 1, 3, and 4 weeks after replacement were greater than the action level. These elevated "background" lead levels could indicate release of lead entrained in the interior scales. Total and dissolved lead levels measured from flushed samples at Site MDC-1were all less than 1 ug/L (not shown).

Calculated 1 liter lead level results are displayed in Figures F.124 through F.126. By two weeks after faucet replacement, first liter lead levels were similar to levels measured prior to faucet replacement at Site F.1. At Site F.2, calculated first 1 liter lead results were all above the action level. At this site, faucet replacement had no impact on LCR compliance. Calculated 1 liter lead level results at Site MDC-1 were all low, and also indicate no benefit to faucet replacement at this site.

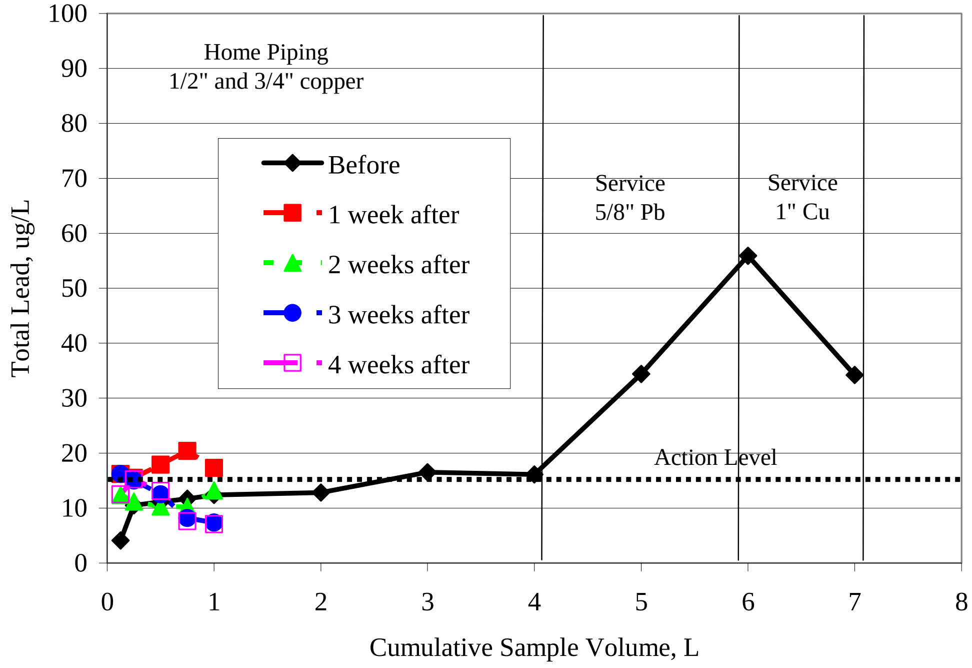


Figure F.110 Site F.1 Total Lead Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

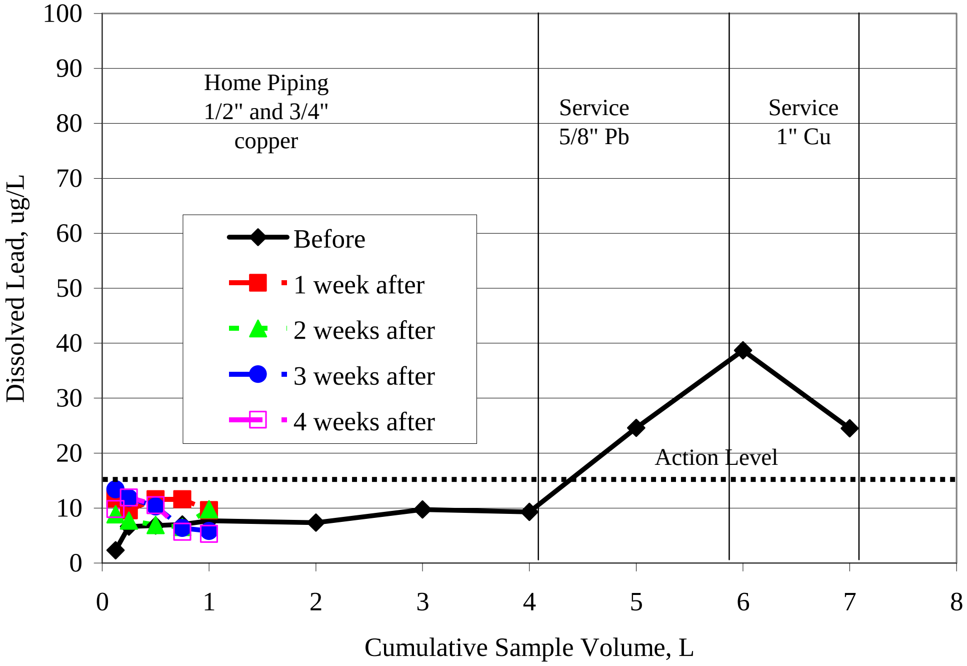


Figure F.111 Site F.1 Dissolved Lead Concentration Profiles (stagnation)

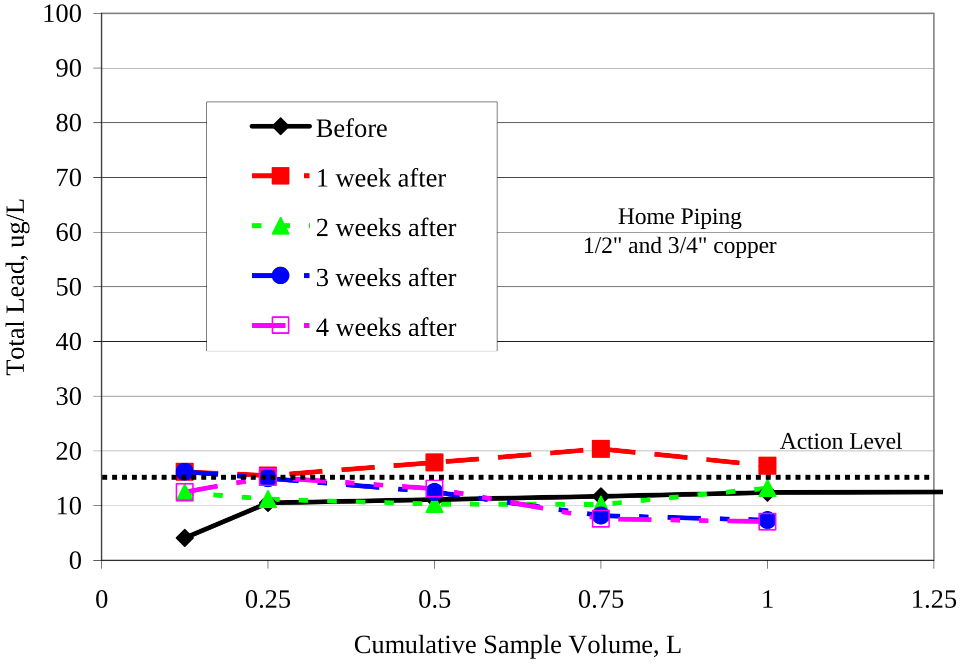


Figure F.112 Site F.1 Total Lead Concentration Profiles – First Liter (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

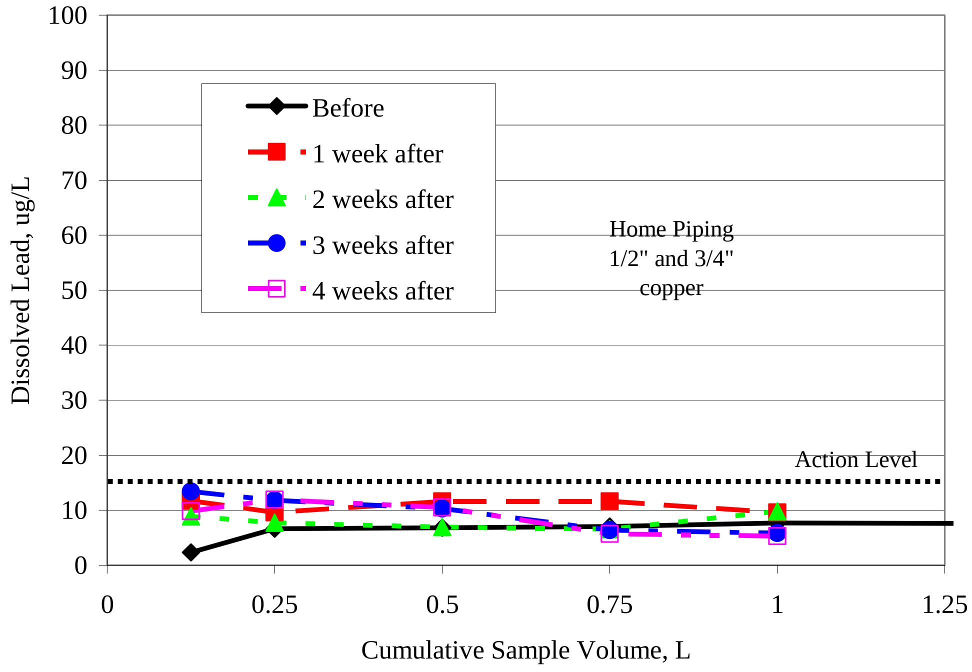


Figure F.113 Site F.1 Dissolved Lead Concentration Profiles – First Liter (stagnation)

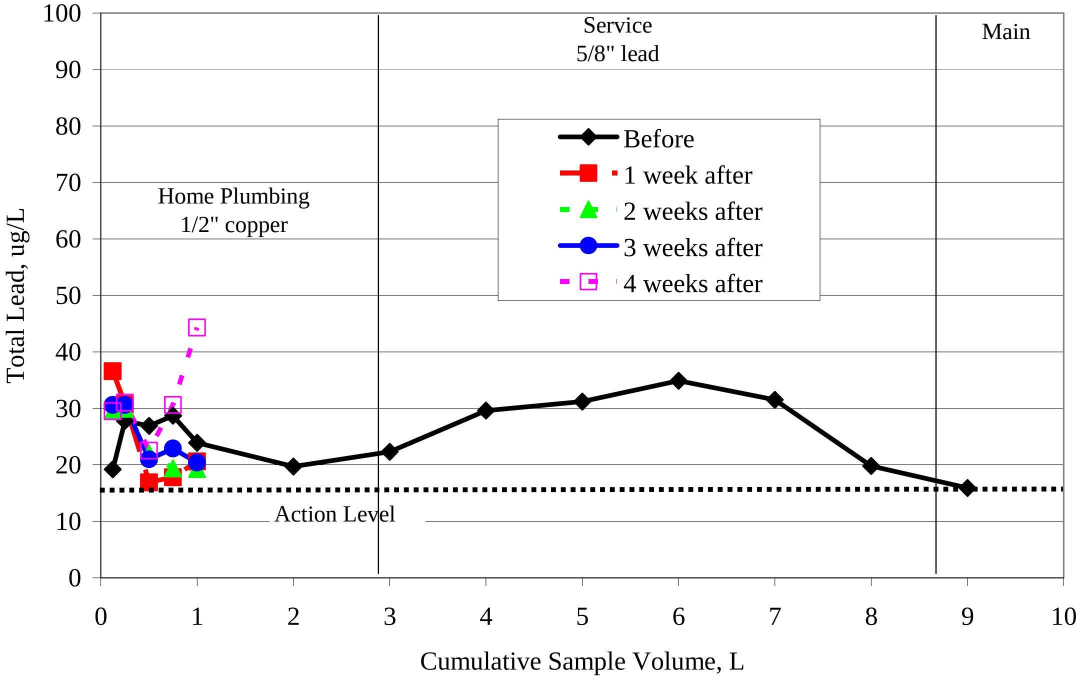


Figure F.114 Site F.2 Total Lead Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

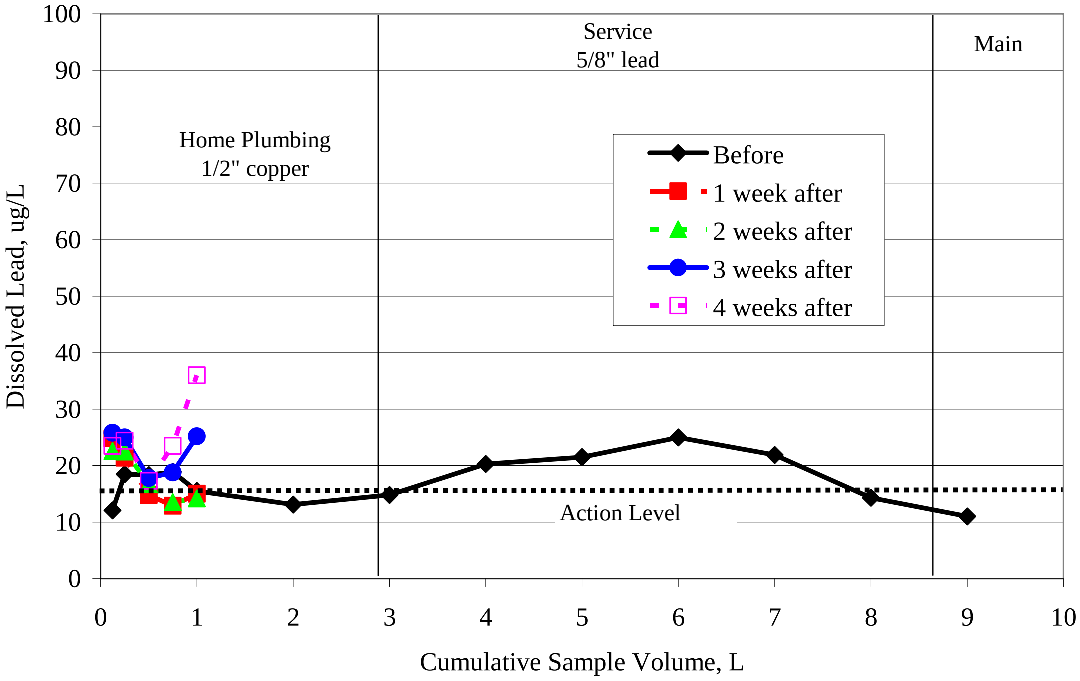


Figure F.115 Site F.2 Dissolved Lead Concentration Profiles (stagnation)

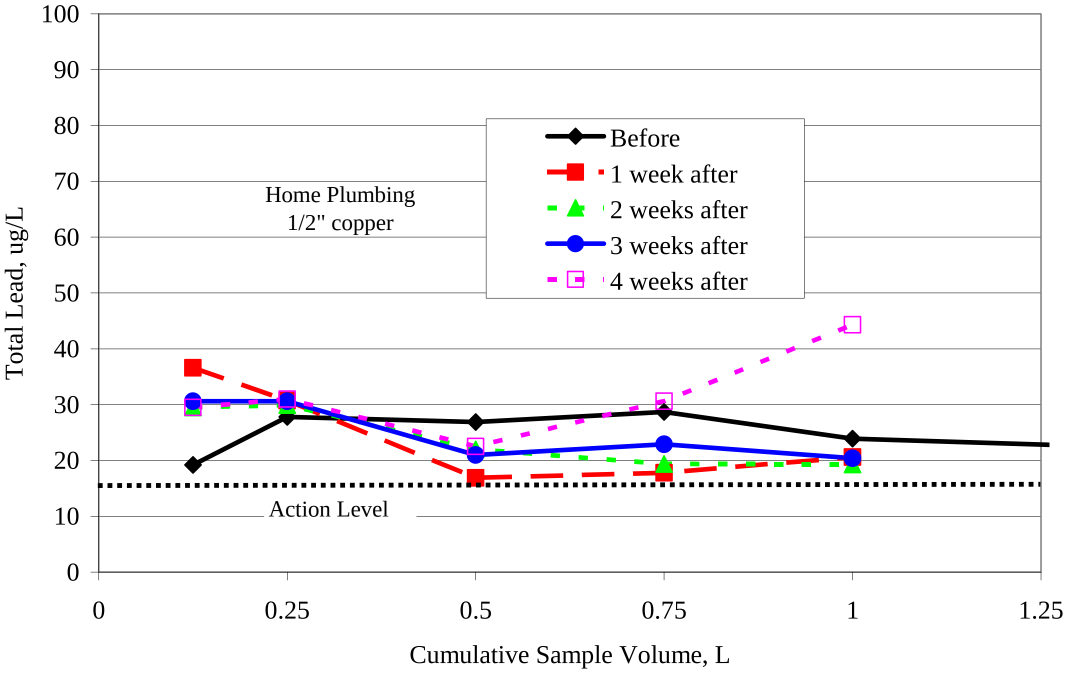


Figure F.116 Site F.2 Total Lead Concentration Profiles – First Liter (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

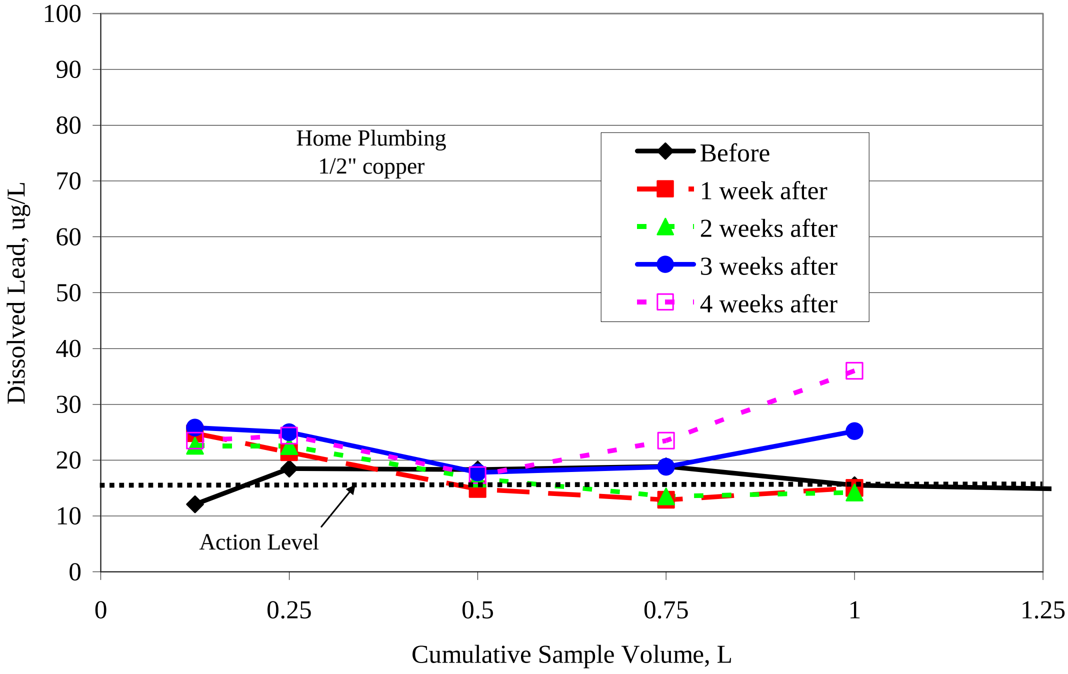


Figure F.117 Site F.2 Dissolved Lead Concentration Profiles – First Liter (stagnation)

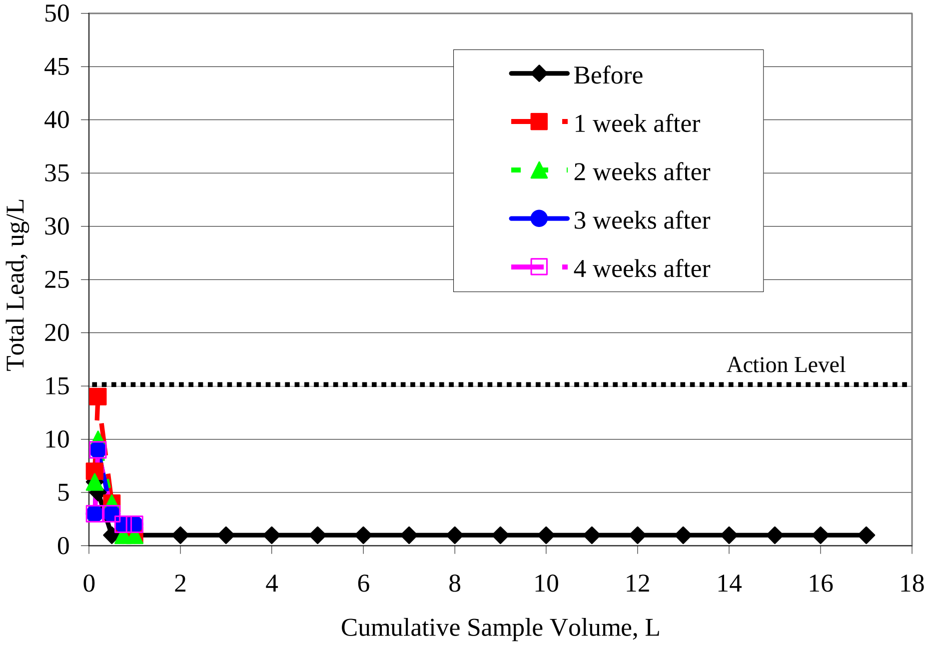


Figure F.118 Site MDC-1 Total Lead Concentration Profiles (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

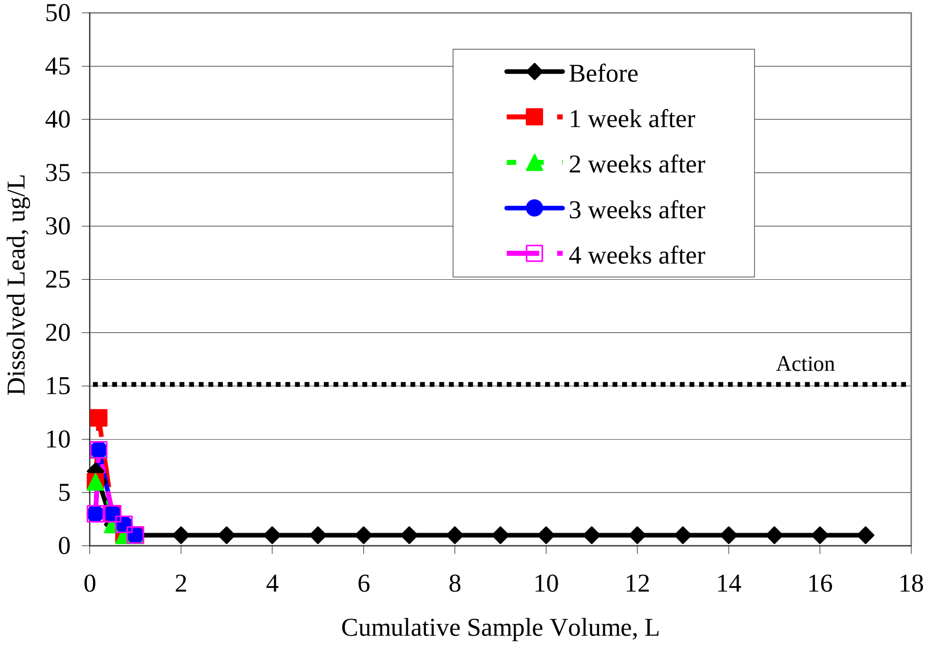


Figure F.119 Site MDC-1 Dissolved Lead Concentration Profiles (stagnation)

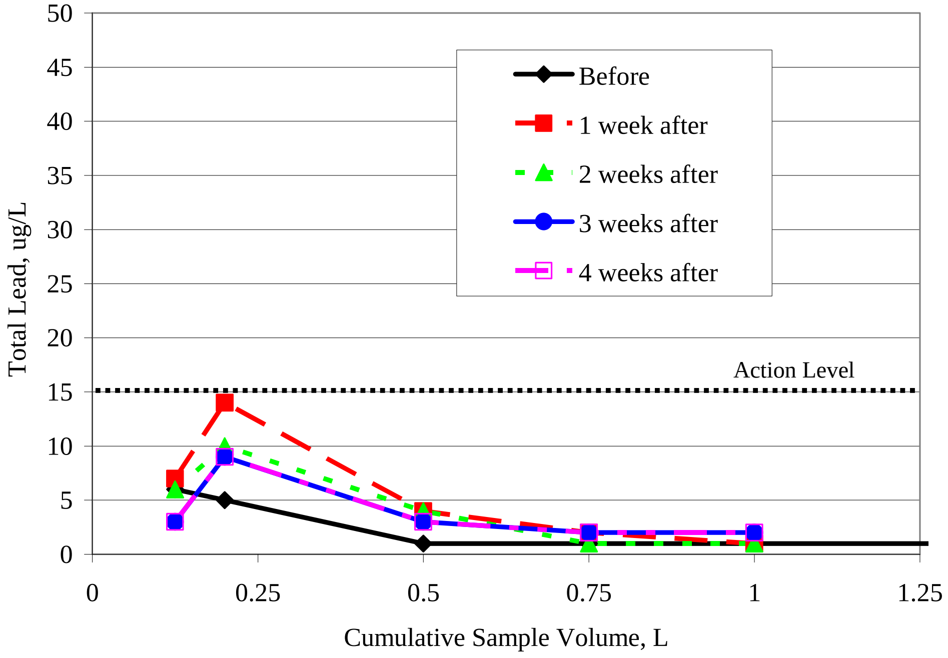


Figure F.120 Site MDC-1 Total Lead Concentration Profiles – First Liter (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

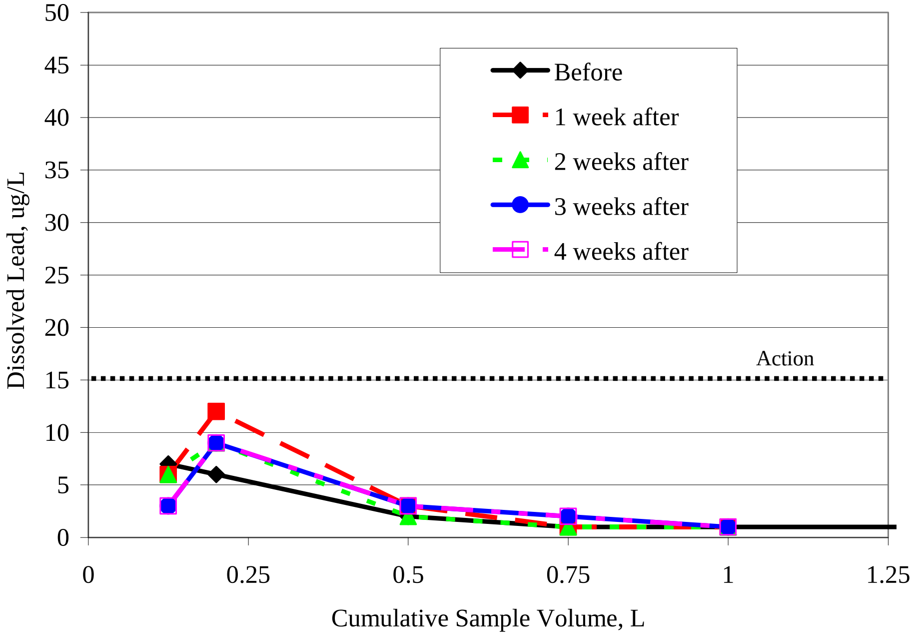


Figure F.121 Site MDC-1 Dissolved Lead Concentration Profiles – First Liter (stagnation)

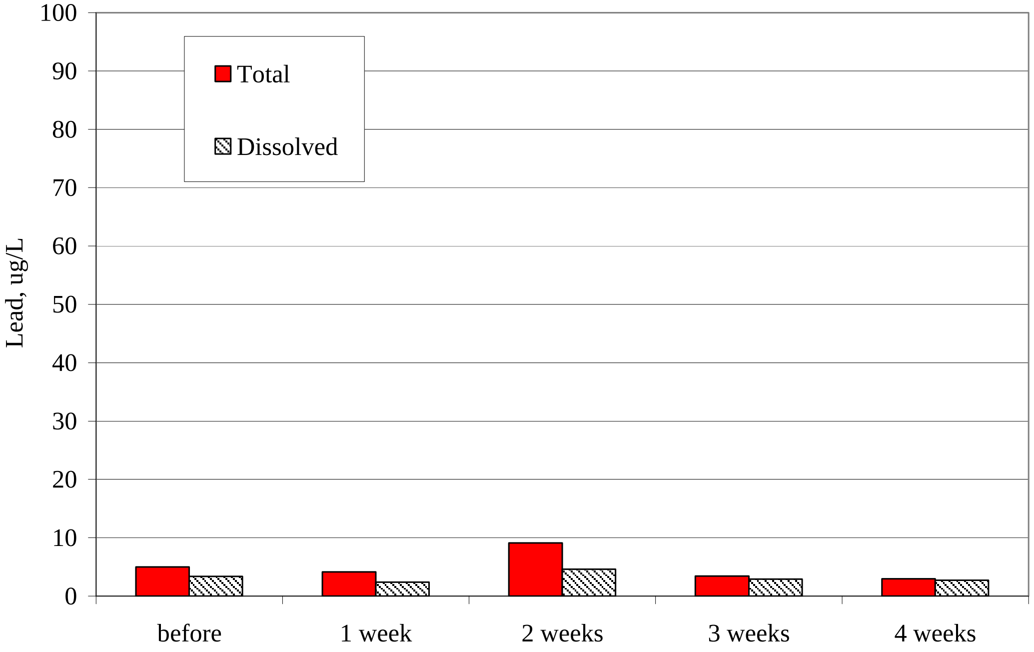


Figure F.122 Site F.1 Total and Dissolved Lead from Flushed Samples

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

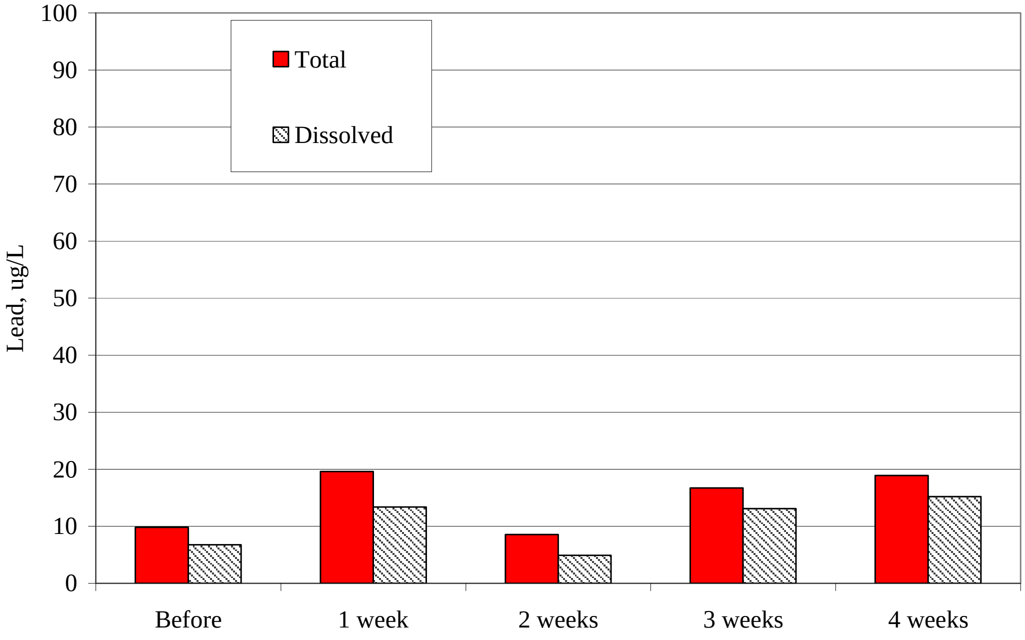


Figure F.123 Site F.2 Total and Dissolved Lead Levels from Flushed Samples

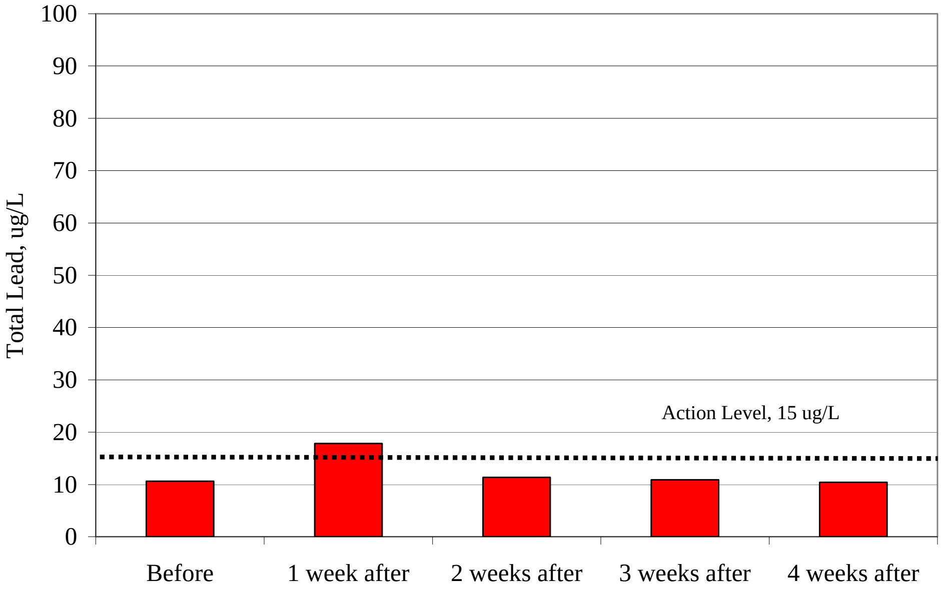


Figure F.124 Site F.1 Calculated First Liter Lead Levels (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

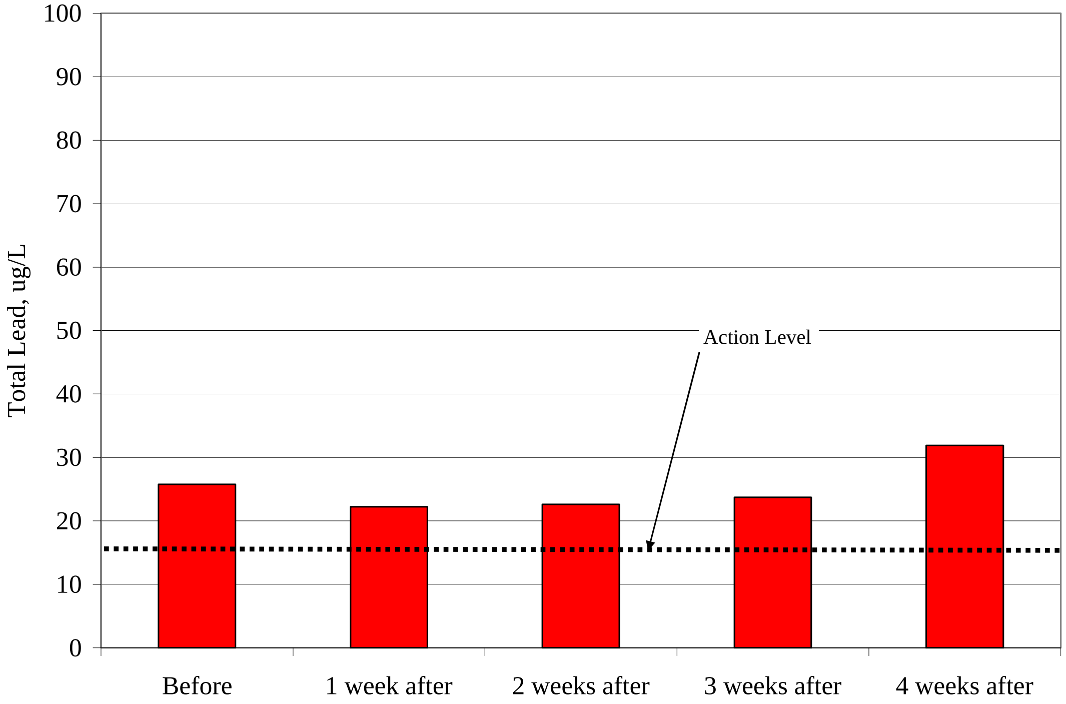


Figure F.125 Site F.2 Calculated First Liter Lead Levels (stagnation)

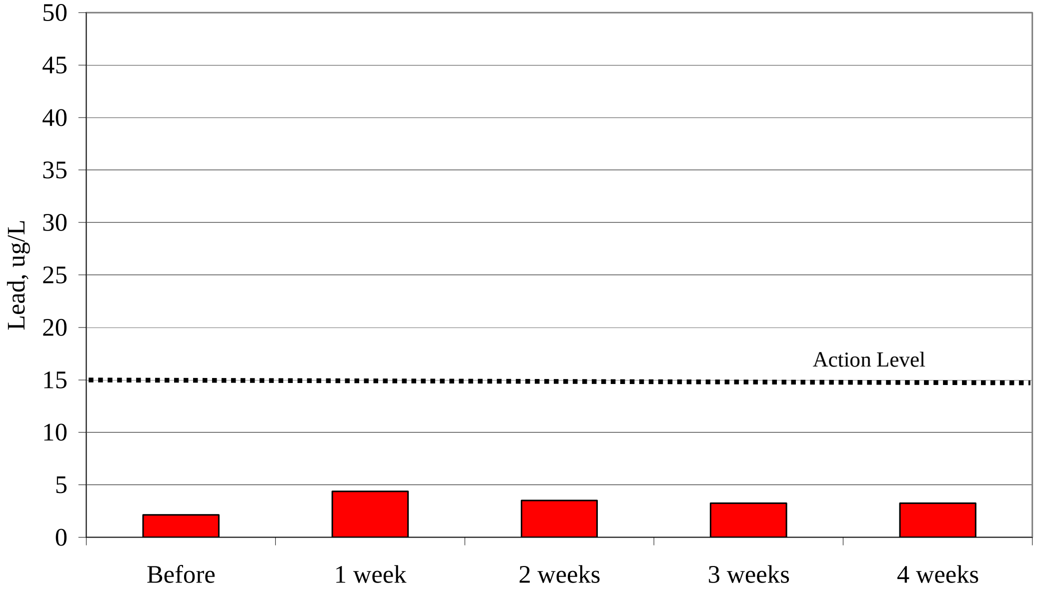


Figure F.126 Site MDC-1 Calculated First Liter Lead Levels (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scale Analysis. The brass faucets removed at Framingham and the MDC were provided to the University of Cincinnati for scale analysis. Table F.60 lists the laboratory numbers assigned to each of these specimens. Scales amounts were generally too small for x-ray diffraction or x-ray fluorescence, so the analytical methods used were SEM-EDS and Raman spectroscopy.

Table F.60
Specimens Received from Framingham and MDC for Scale Analyses

Street address	Laboratory number	Description
F.1	08_FB02	Brass faucet
F.2	08_FB06	Brass faucet
MDC-1	09_FB01	Brass faucet

Water chemistry. Framingham receives water from the Massachusetts Water Resources Authority (MWRA) and the MDC Hartford uses water from the Farmington River and its tributaries stored in the Berkhamsted and Nepaug Reservoirs. MWRA uses pH adjustment for corrosion control, whereas the Hartford MDC uses orthophosphate/polyphosphate addition. A summary of water quality characteristics in the distributed water and selected parameters measured at each site before faucet replacement are listed in Table F.61.

Table F.61
Summary of Distribution and Site Water Quality from MWRA and Hartford MDC

Parameter	Units	MWRA Distribution	Site F.1	Site F.2	MDC Distribution	Site MDC-1
pH		9.4	8.9		7.7	7.5
Chloride	mg/l	24.2			7.24	11.0
Orthophosphate	mg/l as PO4	0.008	-	-	0.88	1.17
Sulfate	mg/l	7.9	-	-	5.35	6.11
Calcium	mg/l	5.81	-	-	-	11.8
Magnesium	mg/l	1.05	-	-	-	1.64
Potassium	mg/l	1.08	-	-	-	0.94
Sodium	mg/l	31.8	-	-	4.2	6.02
Silica	mg/l as SiO2	4.19	-	-	-	1.32
Aluminum	µg/l	28.3	-	-	-	110
Iron	µg/l	53.3	-	-	20.0	47
Lead	µg/l	-	12.1	2.31	-	2

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scale properties. Sites F.1 and F.2. Scales were developed on internal brass surfaces, in some cases completely covering the surface, but more usually as patches of scale surrounded by exposed brass. A macrophotograph of the interior surfaces of faucets 08_FB02 and 08_FB06 (Site F.1 and F.2) is shown in Figure F.127. The brass in faucet FB02 (Site F.1) has a Zn/Cu ratio of 0.42 and a Pb content of 2.9%. The white scale visible in the photograph is hydrozincite [$Zn_5(OH)_6(CO_3)_2$]. Sample FB06 (Site F.2) had a Zn/Cu ratio of 0.58 and Pb content of 4.2%. Figure F.128 shows a closer view of the brass supply tubes for faucet 08_FB02 (Site F.1). The cold water supply (left) is dominated by greenish malachite ($CuCO_3$) and white Zn oxide/carbonate with an underlayer of red cuprite (Cu_2O), whereas the hot water supply (right) is dominated by dark brown tenorite (CuO) and white Zn oxide/carbonate. In SEM imaging, the scale is texturally simple and chemically homogeneous (Figure F.129).

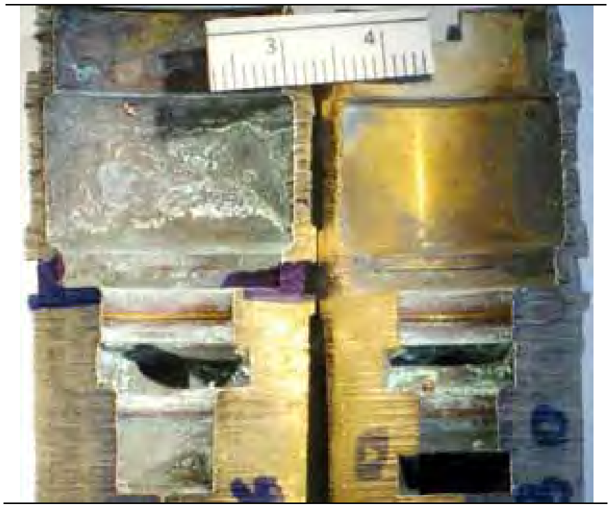


Figure F.127 Macrophotograph of Interior Surfaces of Faucets at Site F1 (left) and F2 (right)

Figure F.128 Brass Supply Tubes for Faucet 08_FB02 (Site F.1). The cold water supply (left) and hot water supply (right)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

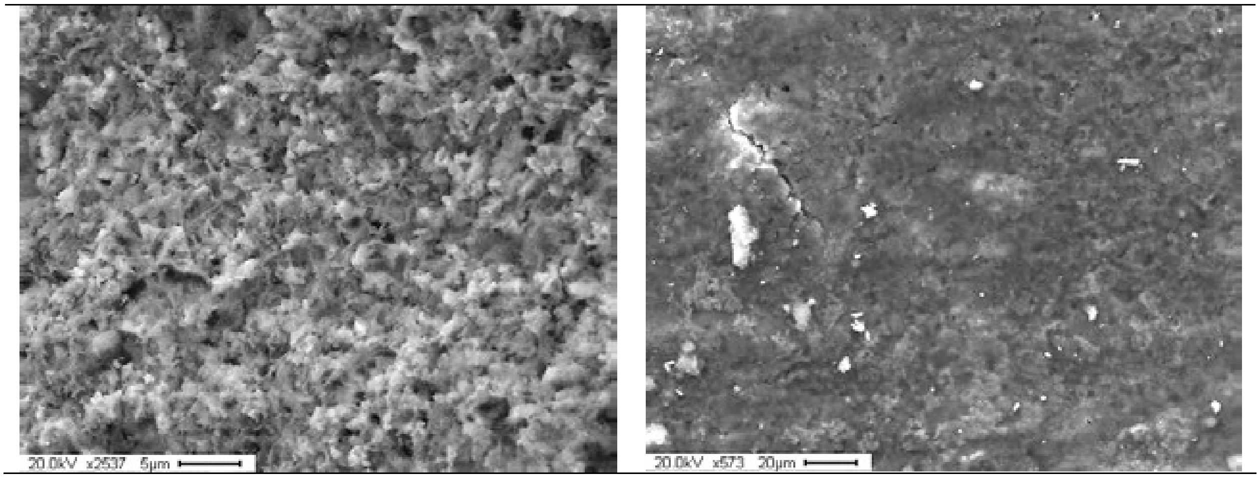


Figure F.129 SEM Image of Copper Oxide Scale Overlying Brass in 08_FB02 (Site F.1). Cold water inlet on left, hot water on right.

The scale on faucet 08_FB02 (Site F.1) proved to be highly variable in Zn and Pb contents in samples collected horizontally across the scale surface (Table F.62), ranging from nearly pure Cu oxide to nearly pure Zn oxide. Pb content was appreciable and ranged from 2% to more than 20%. In general, the Zn and Pb contents of the scales were higher than the Zn and Pb contents of the brass material, which suggests preferential dissolution of those two components, and that they are locally reprecipitated in the scale. The Pb-rich scale portions could be important contributors to particulate Pb concentrations at the tap.

Table F.62
Sample 08_FB02 (Site F.1) Scale Compositions as Determined by Energy Dispersive Spectroscopy (wt %)

Element	**Weight Percentage**[1]							
	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Spot 6	Spot 7	Spot 8
O	10.6	32.7	21.6	15.3	22.8	23.0	25.6	3.73
Si	1.56	8.51	5.47	1.82	3.51	0.37	0.26	0.10
Fe	1.45	0.51	6.27	1.65	3.05	0.53	0.73	0.81
Cu	76.6	1.77	2.97	67.8	30.5	1.43	1.86	1.68
Zn	7.60	51.0	52.9	4.71	22.8	59.5	51.7	69.8
Pb	1.77	5.51	6.06	8.21	13.7	14.1	17.5	23.0
Zn/Cu	0.10	28.8	17.8	0.07	0.75	41.6	27.8	41.5

[1] Spot 1through Spot 8 are scales samples collected horizontally across the surface of the scale

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

The scales in faucet FB06 (Site F.2) were qualitatively similar to those in FB02 (Site F.1), but contained lower amounts of Zn and Pb. On the other hand, they contained significant amounts of additional components such as Ca, Mg, and Si (Table F.63). Figure F.130 displays a photograph of the brass supply tube for faucet 08_FB06 (Site F.2). The scale covered about 2/3 of the brass surface and consisted of dark brown tenorite and white and green zinc oxide/carbonate and copper carbonates. Figure F.131 contains SEM images of the brass supply tube for faucet 08_FB06 (Site F.2). The left image is a Cu oxide rich scale and the right image is a Zn oxide rich scale. Both areas have Pb in the 8-10 % range.

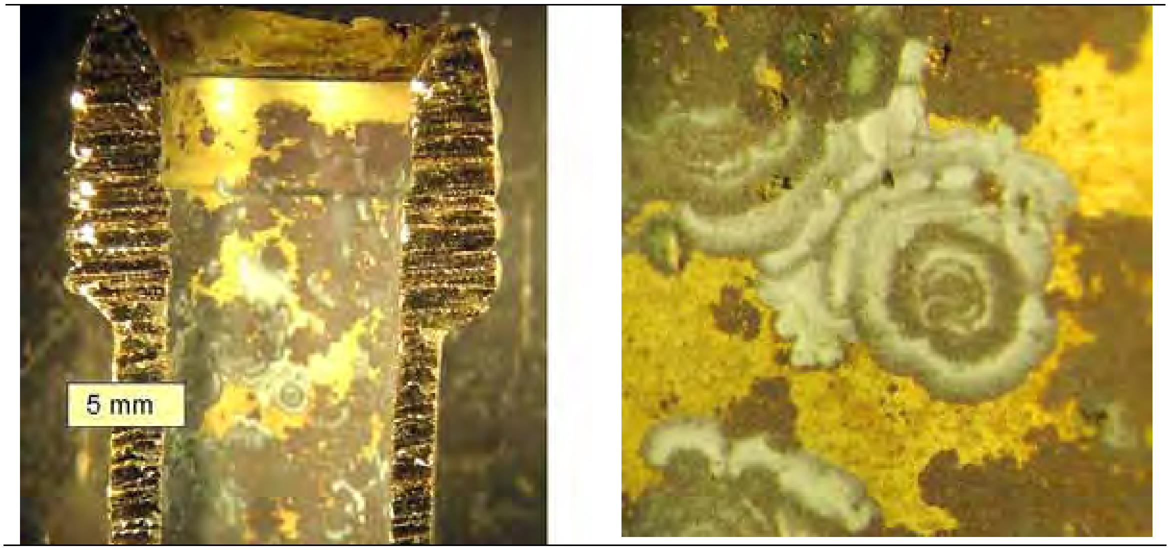


Figure F.130 Brass Supply tube for faucet 08_FB06 (Site F.2).

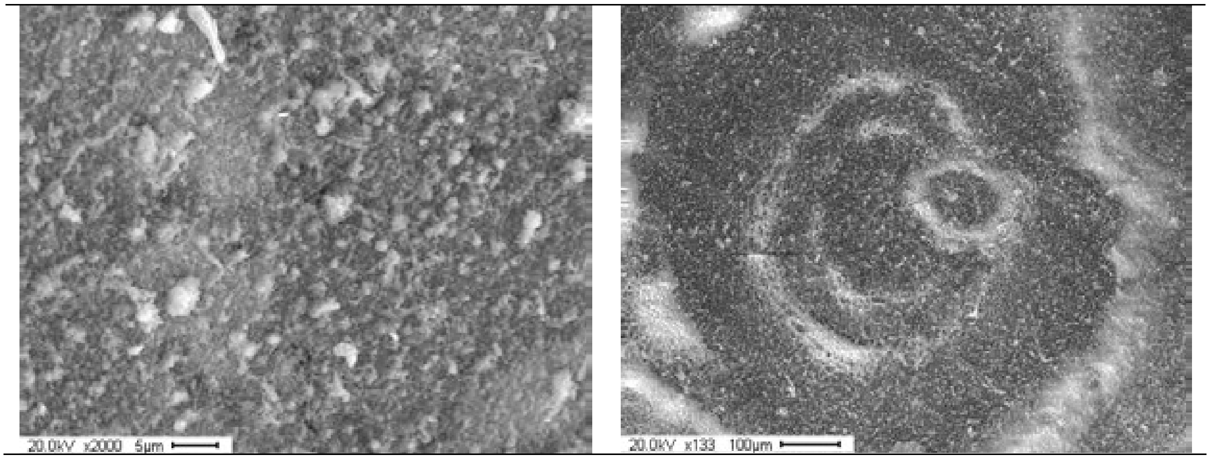


Figure F.131 SEM Images of Brass Supply Tube for Faucet 08_FB06 (Site F.2).

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.63
Scale Compositions of Sample 08_FB06 (Site F.2) as Determined by Energy Dispersive Spectroscopy (wt %)

Element	**Weight Percentage**[1]					
	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Spot 6
C	9.60	7.19	15.1	18.9	9.52	12.1
O	19.3	21.3	29.6	18.8	14.2	21.3
Mg	0.74	0.53	0.65	0.55	0.44	0.45
Al	0.49	0.31	0.54	0.22	0.33	0.50
Si	3.46	3.91	7.29	3.25	2.89	4.10
P	0.39	0.07	0.11	0.08	0.22	0.22
Ca	0.41	0.38	0.39	0.71	0.18	0.25
Fe	0.95	0.99	0.77	1.39	1.16	0.75
Cu	53.8	43.6	14.0	21.9	43.7	20.4
Zn	8.72	19.6	29.3	30.1	18.4	29.6
Pb	1.68	2.10	2.10	4.00	8.51	9.92
Zn/Cu	0.16	0.45	2.10	1.37	0.42	1.45

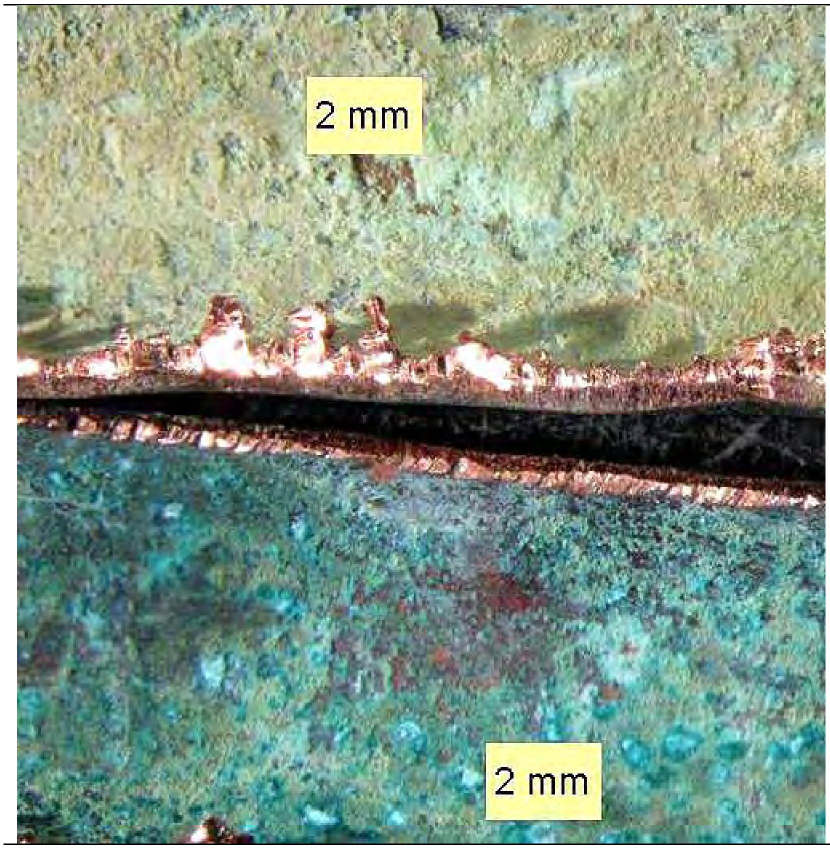
[1] Spot 1through Spot 6 are scales samples collected horizontally across the surface of the scale

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Scale properties. Site MDC-1. The faucet from Site MDC-1 had a relatively continuous scale that extended from the copper supply lines into the interior brass surfaces. The scale appearance was similar on both brass and copper, but varied between the hot and cold water sides (Figures F.132 and F.133). X-ray diffraction of scales scraped from the copper supply lines showed mostly amorphous or poorly crystalline phases with some cuprite (Cu_2O).

Figure F.132 Macrophotograph of Iinterior of Faucet 09_FB01 from site MDC-1.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.



Hot side – X-ray diffraction shows poorly crystalline Cu sulfates.

Cold side -- X-ray diffraction shows amorphous Cu carbonates or sulfates with a small amount of crystalline cuprite.

Figure F.133 Photomicrograph of Cu Supply Lines for Sample 09_FB01 (MDC-1).

PHREEQC modeling. A speciation-saturation state model was constructed for the water compositions measured at the Framingham sites, supplemented with data from MWRA for the system (Table F.64), and for the Hartford site using some MDC data with data from the site. The oxidation state was set at the upper stability limit for water, based on the presence of free chlorine at each site. This procedure underestimates the oxidation state of the system somewhat, but is the maximum allowed by the model. The mineral most affected is plattnerite, which is probably more stable than shown in the model results. A variety of Cu, Fe, and Mn oxides were supersaturated in the water from Framingham sites F1 and F2. Of the possible Pb minerals, only plattnerite and chloro-pyromorphite were at saturation. Cerussite and hydrocerussite were close to saturation for F1 but not F2. Of the copper minerals, malachite and tenorite were strongly supersatured, consistent with their common presence as scale components on copper and brass plumbing components. The zinc oxide, zincite, was close to saturation, again consistent with its appearance in the scales.

Table F.64
Saturation Index (SI) for Likely Scale Minerals in the MWRA Framingham Distribution System

Mineral	Formula	Site F1	Site F2
Supesaturated			
Goethite	FeOOH	5.66	5.66
Manganite	MnOOH	3.87	3.87
Malachite	Cu2(OH)2CO3	2.56	2.56
Hydroxylapatite	Ca5(PO4)3OH	2.44	2.44
Tenorite	CuO	2.03	2.03
Ferrihydrite	Fe(OH)3	2.94	2.94
Brochantite	Cu4(OH)6SO4	1.51	1.51
Azurite	Cu3(OH)2(CO3)2	1.26	1.26
Saturated			
Pyromorphite-Cl	Pb5(PO4)3Cl	4.27	0.67
Plattnerite	PbO2	0.46	-0.26
Calcite	CaCO3	-0.17	-0.17
Zincite	ZnO	-0.53	-0.53
Langite	Cu4(OH)6SO4:H2O	-0.70	-0.70
Cerussite	PbCO3	-0.71	-1.43
Hydrocerussite	Pb3(OH)2(CO3)2	-0.45	-2.61
Undersaturated			
Barite	BaSO4	-1.41	-1.41
Smithsonite	ZnCO3	-1.50	-1.50
Litharge	PbO	-4.26	-4.98
Pyromorphite-OH	Pb5(PO4)3OH	-5.30	-8.89
Cuprite	Cu2O	-15.8	-15.8

Based on 1st draw sample after >6 hours stagnation

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

For site MDC-1, most phases were undersaturated (Table F.65) reflecting the lower pH and alkalinity for this system. Chloro-pyromorphite, however, was strongly supersaturated, a reflection of orthophosphate addition during water treatment. Malachite and tenorite were just saturated in the water, and so may or may not form depending on local temperature and alkalinity variations.

Table F.65
Saturation Index (SI) for Likely Scale Minerals in the Hartford MDC Distribution System

Mineral	Formula	Site MDC-1
Supesaturated		
Pyromorphite-Cl	Pb5(PO4)3Cl	8.26
Goethite	FeOOH	5.10
Ferrihydrite	Fe(OH)3	2.35
Hydroxylapatite	Ca5(PO4)3OH	1.13
Saturated		
Malachite	Cu2(OH)2CO3	0.77
Tenorite	CuO	0.51
Undersaturated		
Brochantite	Cu4(OH)6SO4	-1.44
Azurite	Cu3(OH)2(CO3)2	-1.46
Plattnerite	PbO2	-1.70
Cerussite	PbCO3	-1.99
Calcite	CaCO3	-2.35
Pyromorphite-OH	Pb5(PO4)3OH	-2.47
Langite	Cu4(OH)6SO4:H2O	-3.57
Smithsonite	ZnCO3	-3.68
Zincite	ZnO	-3.69
Hydrocerussite	Pb3(OH)2(CO3)2	-5.26
Litharge	PbO	-6.54
Cuprite	Cu2O	-19.5

Based on 1st draw sample after >6 hours stagnation

PIPE CUTTING EVALUATION

Site Selection and Sampling Protocol

In order to evaluate various pipe cutting techniques, lead service line replacements (LSLR) were completed at Toronto and Boston. Residential sites with lead service lines were selected using the same criteria used for previous LSL replacement studies, i.e. there were no sites with home water treatment systems, sites were not located on dead end mains, and homeowners agreed to not use water during the stagnation period. A premise piping survey was conducted at each site prior to sampling to determine the material, length and diameter of pipe between the kitchen faucet and the beginning and end of the LSL.

Water samples were collected at the kitchen tap before LSLR, the day of the replacement, and for three consecutive days after LSLR replacement. Sampling consisted of an initial flushed sample (15 minutes +), followed by a series of sequential samples collected after the water was allowed to stagnate for a minimum of 6 hours (Table F.66). All samples were 1 liter in volume. Total and dissolved lead was analyzed on all samples and the kitchen faucet remained open for the entire sampling duration, as opposed to opening and closing the faucet between samples. Aerators remained attached during sampling. Field temperature, pH, conductivity or TDS, total and free chlorine measurements were taken during each sampling event.

Table F.66
Samples Collected for Pipe Cutting Evaluation Study

Sample No.	Volume	Conditions	Before LSLR	Day of LSLR	24 hours, 2 days, and 3 days, after LSLR
1	1 L	Flushed, before stagnation	X	X	X
2	1 L	After stagnation	X		X
3	1 L	After stagnation	X		X
4	1 L	After stagnation	X		X
5	1 L	After stagnation	X		X
6	1 L	After stagnation	X		X
7- 15	1 L	After stagnation	X		X

Table F.67 lists the site survey information for each site. At sites T5 through T13 and Site B-5, partial lead service line replacements occurred, with the exception of Site T7 where due to the complexity of the site, a full replacement was done. At these ten sites, various pipe cutting techniques were utilized during the replacement, and water quality samples were collected at the kitchen faucet (aerator attached). The pipe cutting techniques that were used at these sites (hacksaw and disc cutter) are two methods available for removing service pipe sections.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.67
Site Survey Information for Pipe Cutting Evaluations

Site No.	Location	Piping	Pipe Length, meters	Volume, mL
T-5 (Hacksaw/Partial Replacement)	Kitchen faucet to service line entry to house	1/2” copper 1/2” galvanized	13.0 0.5	1.96 0.10
	Service	1/2” lead	18.0 (14.9 replaced)	2.29 (1.89)
	Total			**4.35**
T-6 (Hacksaw/Partial Replacement)	Kitchen faucet to service line entry to house	1/2” copper	8.0	1.21
	Service	1/2” lead	23.0 (14.9 replaced)	2.92 (1.89)
	Total			**4.13**
T-7 (Hacksaw/Partial Replacement changed to Full Replacement)	Kitchen faucet to service line entry to house	1/2” copper	10.4	1.57
	Service	1/2” lead	9.0 (9.0 replaced)	1.14 (1.14)
	Total			**2.71**
T-8 (Disc/Partial Replacement)	Kitchen faucet to service line entry to house	1/2” copper 3/4” copper	4.7 7.0	0.71 2.18
	Service	1/2” lead 5/8” lead	11.0 9.0 (13.5 replaced)	1.40 2.57 (3.14)
	Total			**6.86**

(continued)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.67 Continued
Site Survey Information for Pipe Cutting Evaluations

Site No.	Location	Piping	Pipe Length, meters	Volume, mL
T-9 (Disc/Partial Replacement)	Kitchen faucet to service line entry to house	1/2” copper	1.4	0.21
		3/4” copper	13.2	4.12
		1/2” galvanized	0.6	0.11
	Service	1/2” lead	18.0 (15.0 m replaced)	2.29 (1.91)
	Total			**6.73**
T-10 (Disc/Partial Replacement)	Kitchen faucet to service line entry to house	1/2” copper	3.3	0.50
		3/4” copper	16.8	5.24
	Service	1” lead (15 m replaced)	21.8 (15.0 m replaced)	11.05 (7.61)
	Total			**16.79**
T-11 (Disc/Partial Replacement)	Kitchen faucet to service line entry to house	1/2” copper	12.6	1.90
	Service	1/2” lead	10.0	1.27
		5/8” lead	11.0 (15.0 m replaced)	3.14 (3.64)
	Total			**6.31**
T-12 (Hack/Partial Replacement)	Kitchen faucet to service line entry to house	1/2” copper	8.9	1.34
		1/2” galvanized	1.2	0.24
	Service	1/2” lead	18.4 (13.5 replaced)	2.34 (1.71)
	Total			**3.92**

(continued)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.67 Continued
Site Survey Information for Pipe Cutting Evaluations

Site No.	Location	Piping	Pipe Length, meters	Volume, mL
T-13 (Hack/Partial Replacement)	Kitchen faucet to service line entry to house	1/2” copper 1/2” galvanized	9.4 0.2	1.42 0.04
	Service	1/2” lead	19.2 (12.6 m replaced)	2.44 (1.60)
	Total			**3.90**
B-5 (Disc/Full Replacement)	Kitchen faucet to meter	1/2” copper 5/8” copper	16.75 1.46	0.77 0.10
	Service	3/4” lead	20.58	1.79
	Total			**2.66**

Results

Water Quality. Analysis of a variety of water quality parameters were completed on flushed and stagnation samples at the pipe cutting sites. Alkalinity, pH, total and free chlorine levels were consistent among sites in Toronto, as were ORP measurements (Figure F.134). Site B-5 exhibited water quality similar to other LSLR sites sampled in Boston for this project. Tables F.68 through F.77 lists the water quality parameters measured at each site.

Lead Levels. The majority of lead in samples was in the dissolved form, ranging generally from 65% - 100% of the total lead measured (not shown). The exceptions were a limited number of samples collected after LSL replacement where dissolved lead was ~30-40% of the total lead measured. Total lead level results are displayed in Figures F.135 through F.144. The majority of sites measured higher lead levels in sequential samples collected 24 hours after replacement when compared to samples collected before replacement. In most cases, lead levels were lower 2 or 3 days after replacement than levels measured before replacement. Lead levels measured in flushed samples was generally low, with some exceptions (samples collected before replacement at Site T-5 and T-9, and samples collected after replacement at Site T-9 and B-5) (Figure F.145 through F.154). Comparisons of first liter lead levels before and after replacement are shown in Figures F.155 through F.164. In general, none of the sites showed improvement in first liter lead levels by 3 days after the replacement.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

The difference in the total mass of lead measured at the tap from sequential samples collected before and three days after lead service replacement was calculated (Figure F.165). For sites where a disc or pipe cutter was used to cut the service, a greater difference in total mass was calculated when compared to the difference calculated at sites where a hacksaw was used. The hacksaw has a rougher, more irregular cutting surface than the disc cutter, which may cause more disruption of the surface of the pipe and potentially higher lead levels after replacement than a disc cutter.

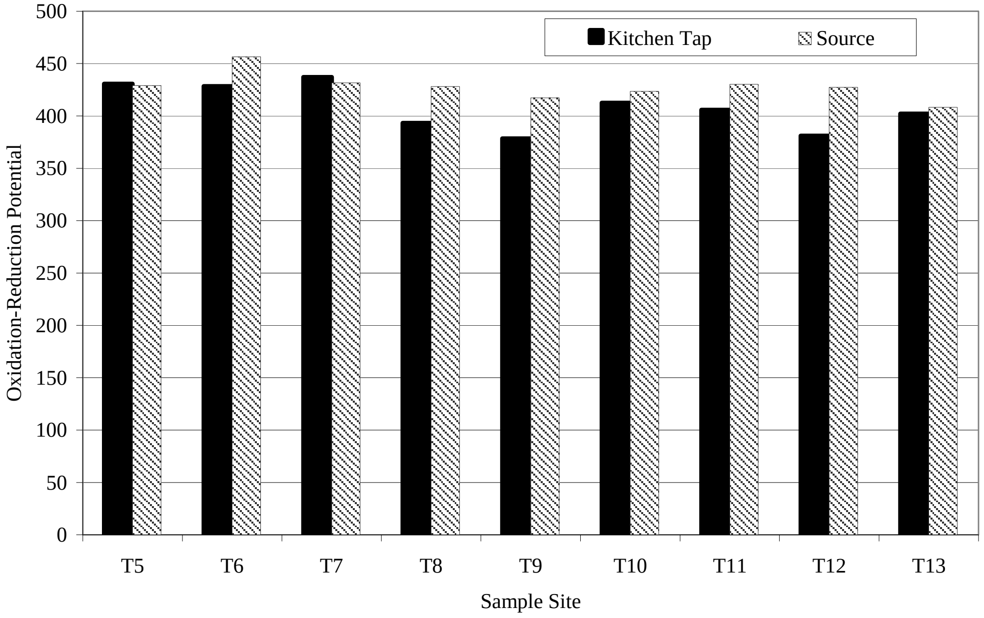


Figure F.134 ORP measurements for Sites T-5 through T-13

Table F.68
Site T-5 Water Quality

		Before LSLR	Day of LSLR - Kitchen	Day of LSLR - Source	24 hours after LSLR	2 days after LSLR	3 days after LSLR
pH		7.37	7.54	7.58	7.52	7.3	7.44
Temp	(as deg.C)	24.8	16.4	16.2	24.6	24	24.5
Cond.	(as µS/cm)	318	316	308	323	323	313
Free Cl2	(mg/L)	0.02	0.01	0.04	0.03	0.03	0.04
Total Cl2	(mg/L)	0.53	0.99	1.02	0.54	0.58	0.52
ORP	(mV)		430.6	429			

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.69
Site T-6 Water Quality

		Before LSLR	Day of LSLR - Kitchen	Day of LSLR - Source	24 hours after LSLR	2 days after LSLR	3 days after LSLR
pH		7.43	7.65	7.61	7.57	7.59	7.51
Temp	(as deg.C)	23	15.8	15.4	22.6	23.3	23
Cond.	(as µS/cm)	314	309	311	317	316	313
Free Cl2	(mg/L)	0.03	0.03	0.06	0.03	0	0.03
Total Cl2	(mg/L)	0.44	0.98	1	0.46	0.42	0.57
ORP	(mV)		428.4	456.5			

Table F.70
Site T-7 Water Quality

		Before LSLR	Day of LSLR - Kitchen	Day of LSLR - Source	24 hours after LSLR	2 days after LSLR	3 days after LSLR
pH		7.45	7.57	7.57	7.54	7.57	7.46
Temp	(as deg.C)	20.7	11.2	11	21	22	22.2
Cond.	(as µS/cm)	313	309	305	312	311	310
Free Cl2	(mg/L)	0.03	0.04	0.05	0.04	0.07	0.04
Total Cl2	(mg/L)	0.92	1.2	1.2	0.98	0.98	1.03
ORP	(mV)		437.1	431.6			

Table F.71
Site T-8 Water Quality

		Before LSLR	Day of LSLR - Kitchen	Day of LSLR - Source	24 hours after LSLR	2 days after LSLR	3 days after LSLR
pH		7.47	7.45	7.58	7.54	7.54	7.54
Temp	(as deg.C)	24.1	19.6	15.4	24	23.2	24.1
Cond.	(as µS/cm)	316	306	304	319	317	317
Free Cl2	(mg/L)	0.03	0.07	0.09	0.02	0.01	0.03
Total Cl2	(mg/L)	0.73	1.13	1.2	0.64	0.61	0.62
ORP	(mV)		393.2	428			

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.72
Site T-9 Water Quality

		Before LSLR	Day of LSLR - Kitchen	Day of LSLR - Source	24 hours after LSLR	2 days after LSLR	3 days after LSLR
pH		7.6	7.64	7.77	7.57	7.43	7.44
Temp	(as deg.C)	22.7	19.2	19	22.6	22.7	22.6
Cond.	(as µS/cm)	314	310	306	312	321	319
Free Cl2	(mg/L)	0.03	0.02	0.04	0.02	0.02	0.02
Total Cl2	(mg/L)	0.7	1.02	1.04	0.84	0.76	0.76
ORP	(mV)		378.5	417.4			

Table F.73
Site T-10 Water Quality

		Before LSLR	Day of LSLR - Kitchen	Day of LSLR - Source	24 hours after LSLR	2 days after LSLR	3 days after LSLR
pH		7.43	7.43	7.44	7.4	7.32	7.3
Temp	(as deg.C)	25.3	18.7	16.1	26.9	26.8	25.1
Cond.	(as µS/cm)	320	308	306	321	323	328
Free Cl2	(mg/L)	0.04	0.08	0.06	0.04	0.02	0.01
Total Cl2	(mg/L)	0.71	1.16	1.17	0.65	0.71	0.28
ORP	(mV)		412.5	423.4			

Table F.74
Site T-11 Water Quality

		Before LSLR	Day of LSLR - Kitchen	Day of LSLR - Source	24 hours after LSLR	2 days after LSLR	3 days after LSLR
pH		7.45	7.59	7.57	7.61	7.45	7.45
Temp	(as deg.C)	20.4	19.8	15.8	22.8	23	19.9
Cond.	(as µS/cm)	326	321	314	317	333	323
Free Cl2	(mg/L)	0.06	0.02	0.04	0.04	0.04	0.04
Total Cl2	(mg/L)	1.06	1.19	1.2	0.81	0.81	1.16
ORP	(mV)		405.7	430.2			

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.75
Site T-12 Water Quality

		Before LSLR	Day of LSLR - Kitchen	Day of LSLR - Source	24 hours after LSLR	2 days after LSLR	3 days after LSLR
pH		7.51	7.44	7.51	7.39	7.36	7.42
Temp	(as deg.C)	22.4	19.6	19.2	23.1	22.6	23.9
Cond.	(as µS/cm)	328	310	308	313	321	310
Free Cl2	(mg/L)	0.01	0.05	0.06	0.02	0.02	0.02
Total Cl2	(mg/L)	0.4	1.16	1.16	1.08	0.85	0.77
ORP	(mV)		381.0	427.3			

Table F.76
Site T-13 Water Quality

		Before LSLR	Day of LSLR - Kitchen	Day of LSLR - Source	24 hours after LSLR	2 days after LSLR	3 days after LSLR
pH		7.36	7.41	7.42	7.43	7.45	7.5
Temp	(as deg.C)	23.6	17.8	17.7	24.1	23.8	23.5
Cond.	(as µS/cm)	317	312	310	316	327	329
Free Cl2	(mg/L)	0.02	0.05	0.05	0.02	0.02	0.02
Total Cl2	(mg/L)	0.38	1.09	1.09	0.40	0.41	0.35
ORP	(mV)		402.2	408.3			

Table F.77
Site B-5 Water Quality

		Before LSLR	Day of LSLR	24 hours after LSLR	2 days after LSLR	3 days after LSLR
pH	(pH units)	9.6	9.7	9.5	9.5	9.5
Temp	(as deg.C)	16.7	18.7	20.1	17.2	17.3
Cond.	(as µmhos/cm)	175.5	179.4	185.2	183.2	181.4
Free Cl2	(mg/L)	0.32	1.69	0.36	1.39	1.34
Total Cl2	(mg/L)	0.55	2.17	0.98	1.43	1.57

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

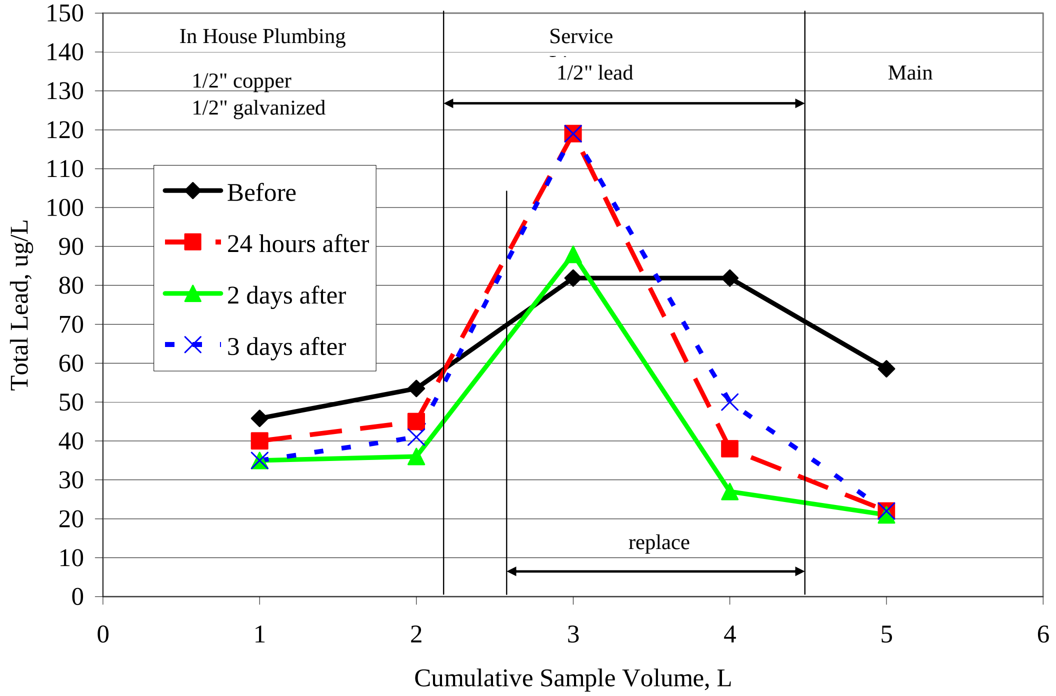


Figure F.135 Total Lead Levels from Stagnation Samples: Site T-5

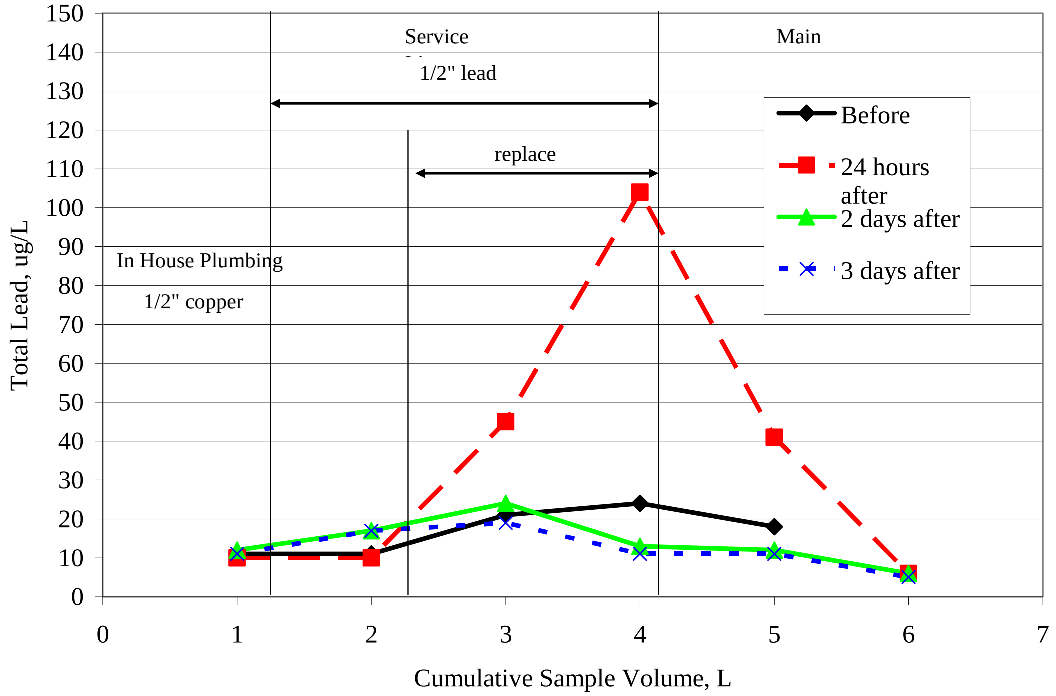


Figure F.136 Total Lead Levels from Stagnation Samples: Site T-6

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

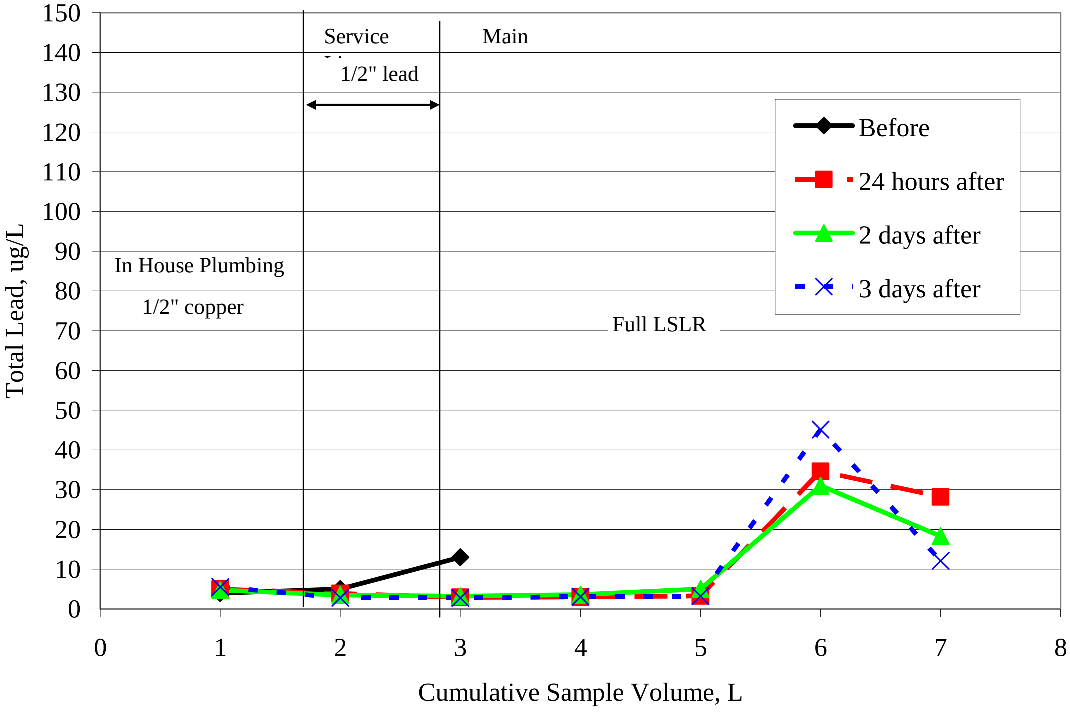


Figure F.137 Total Lead Levels from Stagnation Samples: Site T-7

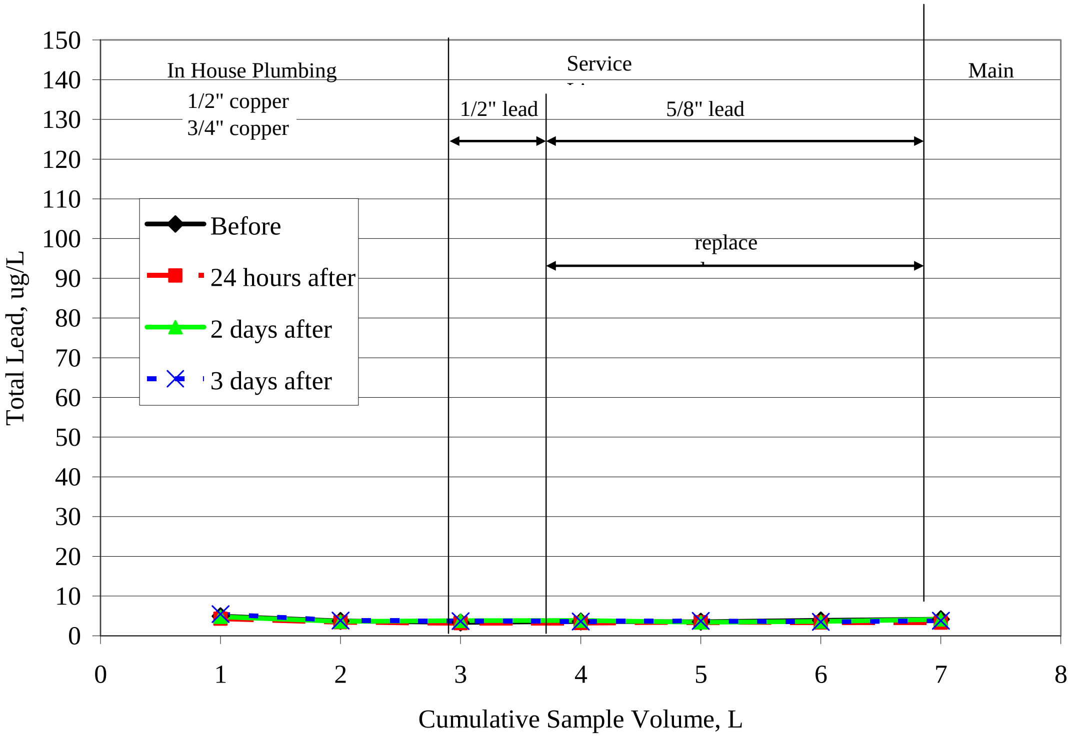


Figure F.138 Total Lead Levels from Stagnation Samples: Site T-8

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

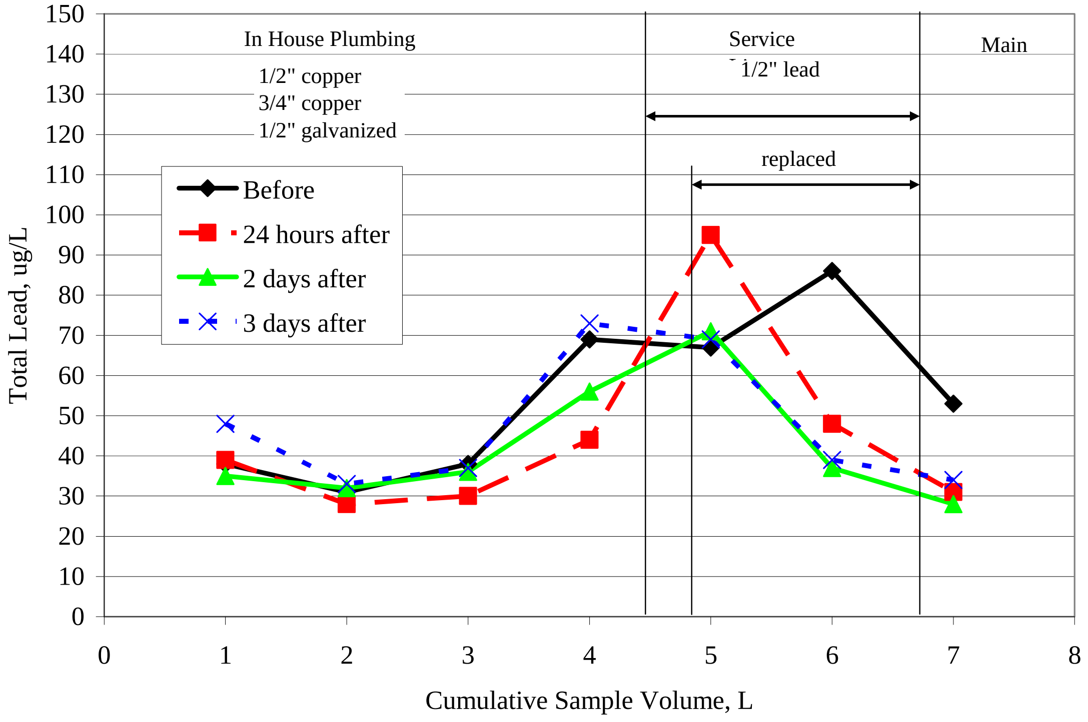


Figure F.139 Total Lead Levels from Stagnation Samples: Site T-9

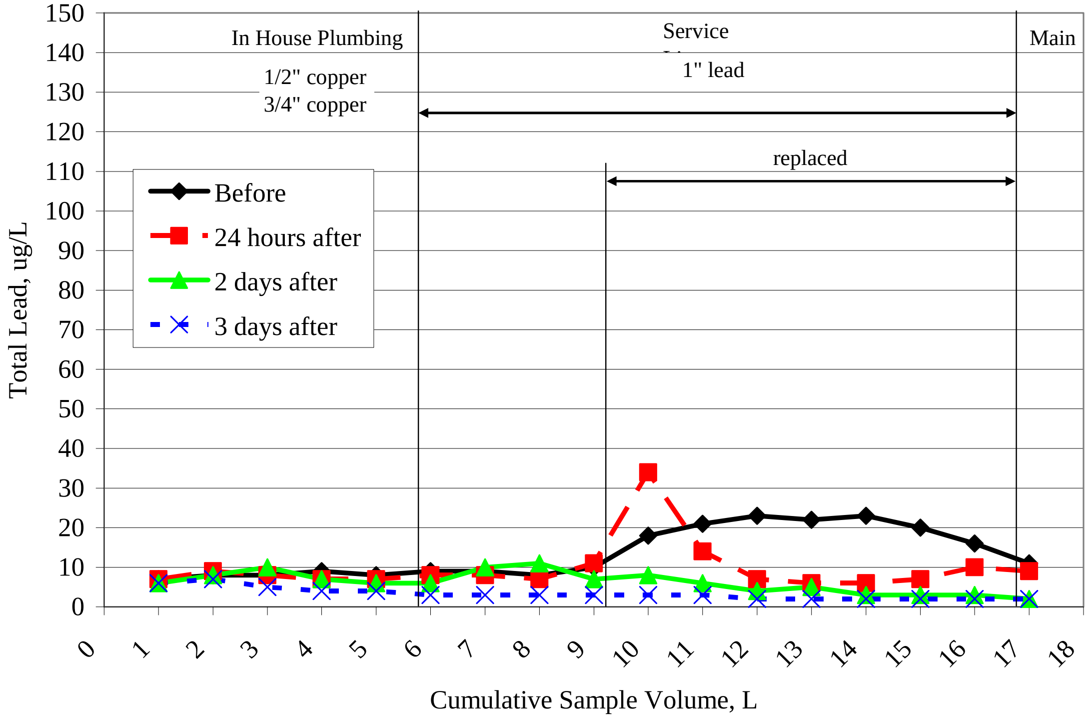


Figure F.140 Total Lead Levels from Stagnation Samples: Site T-10

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

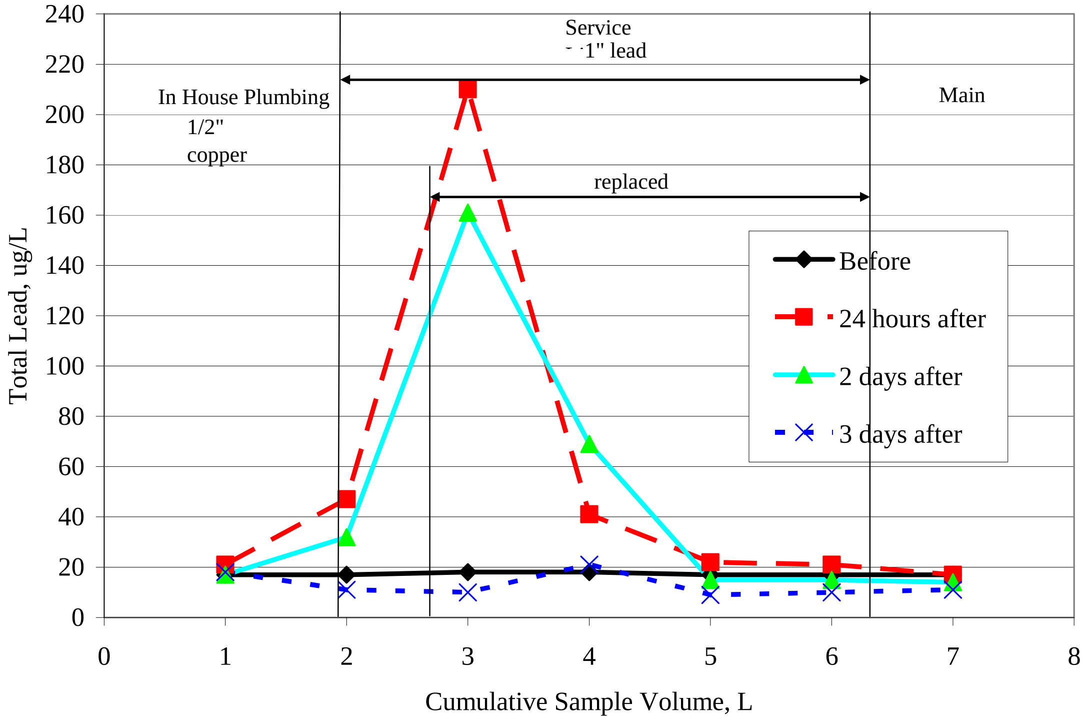


Figure F.141 Total Lead Levels from Stagnation Samples: Site T-11

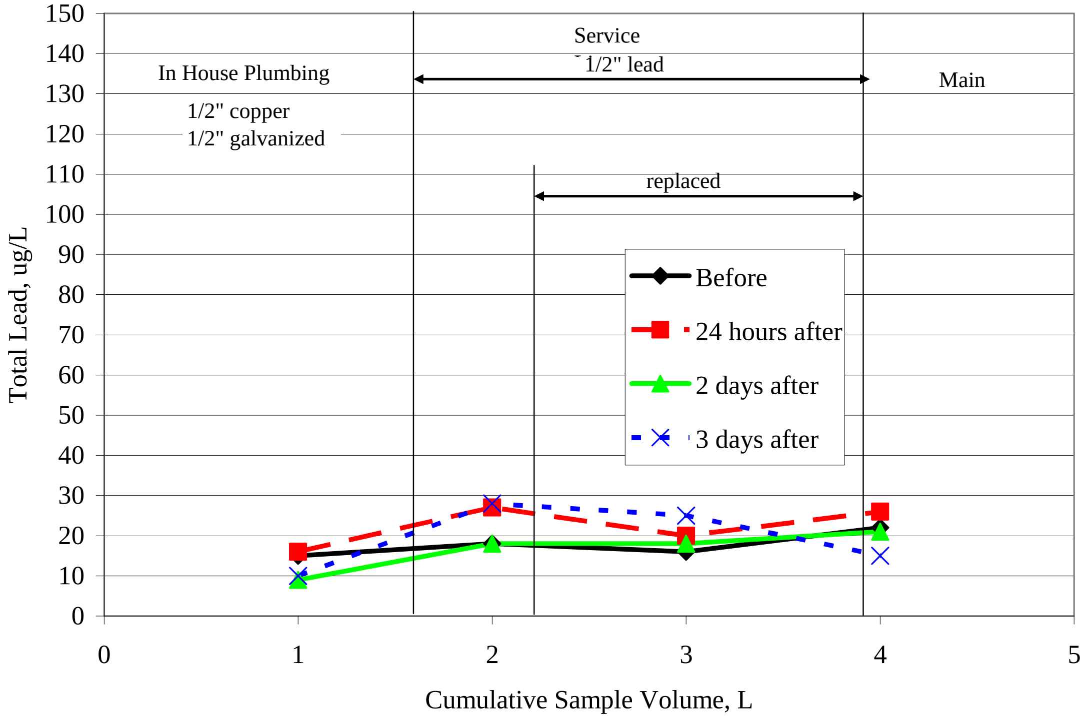


Figure F.142 Total Lead Levels from Stagnation Samples: Site T-12

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

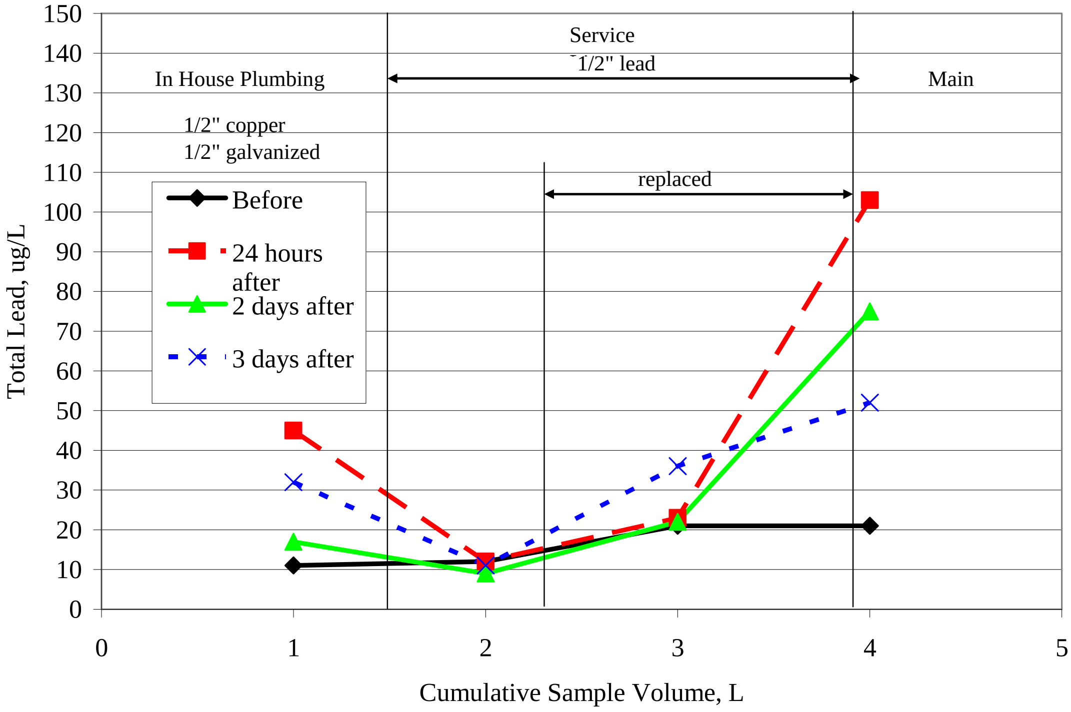


Figure F.143 Total Lead Levels from Stagnation Samples: Site T-13

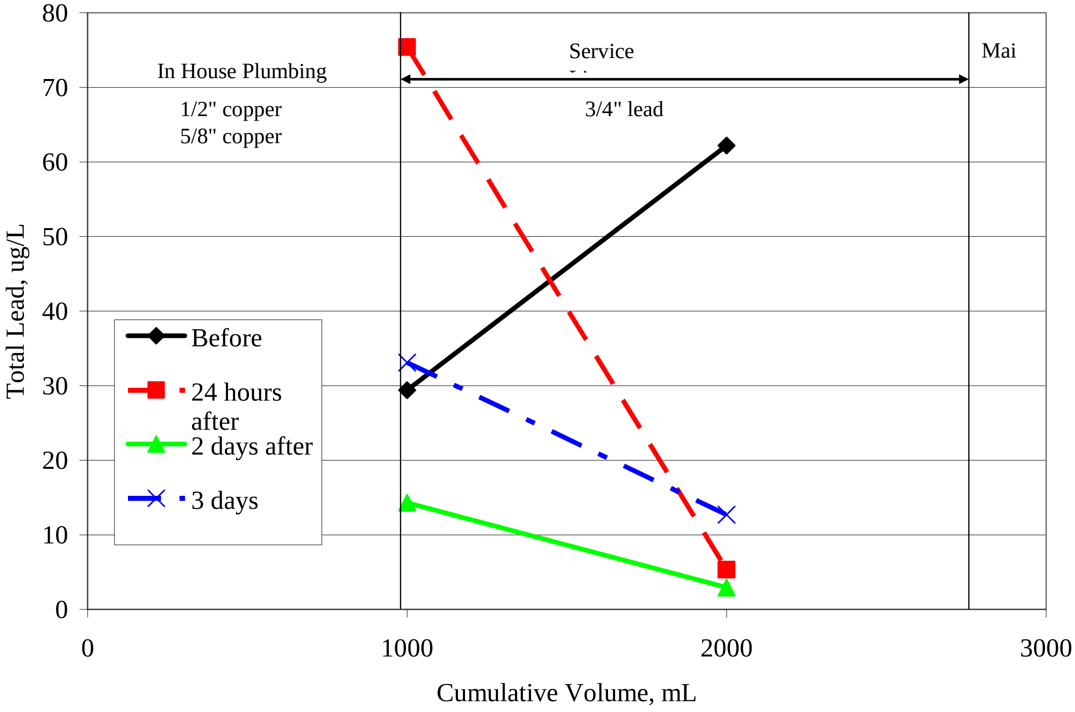


Figure F.144 Total Lead Levels from Stagnation Samples –Site B-5

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

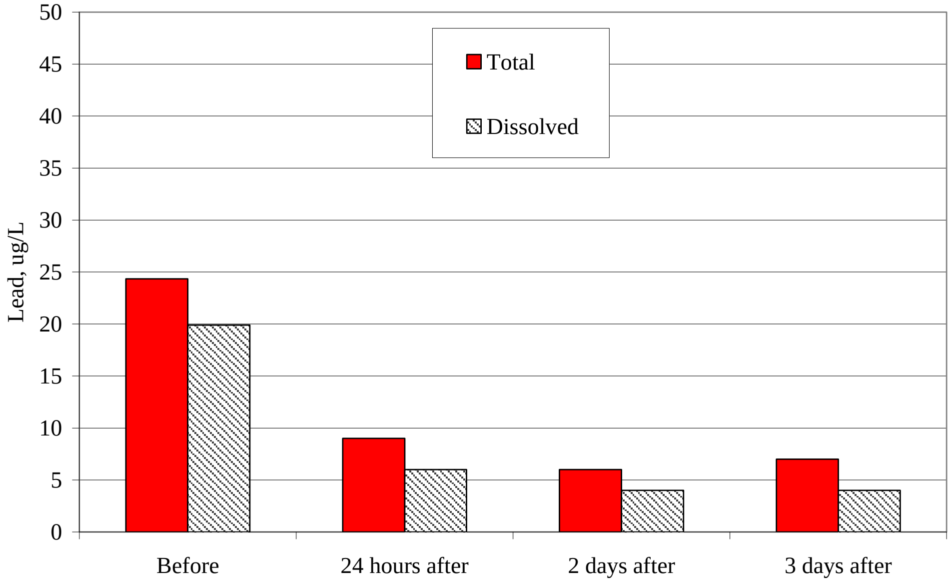


Figure F.145 Total and Dissolved Lead Levels, Flushed Samples: Site T- 5

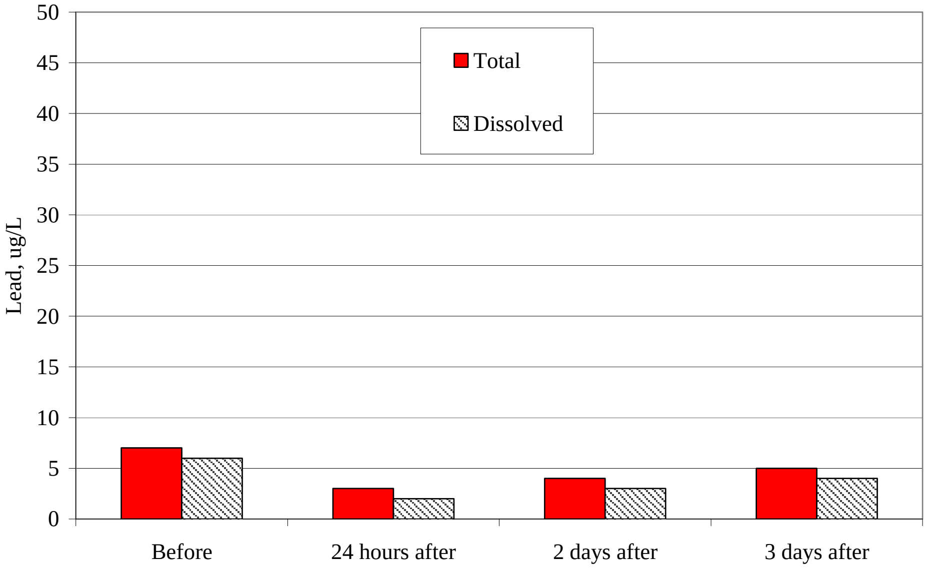


Figure F.146 Total and Dissolved Lead Levels, Flushed Samples: Site T-6

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

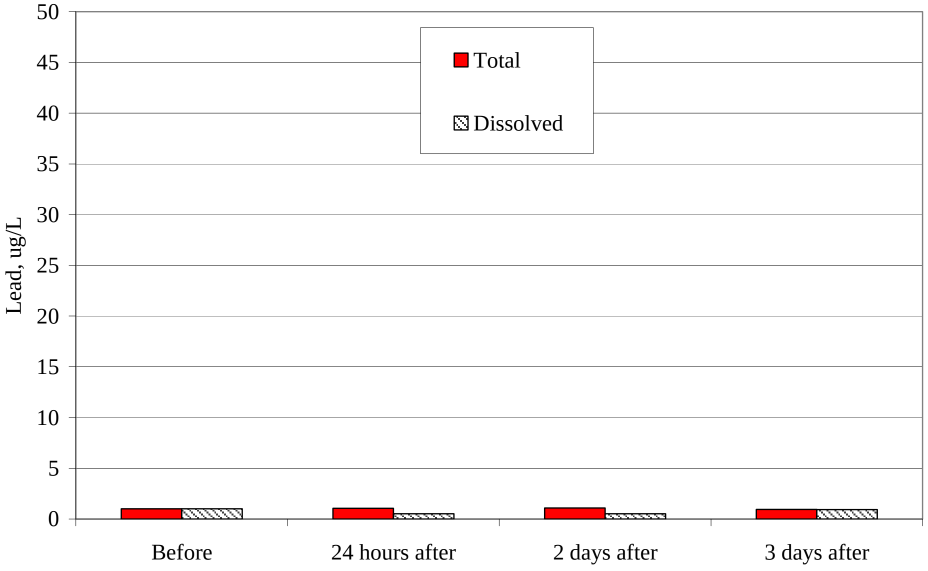


Figure F.147 Total and Dissolved Lead Levels, Flushed Samples: Site T-7

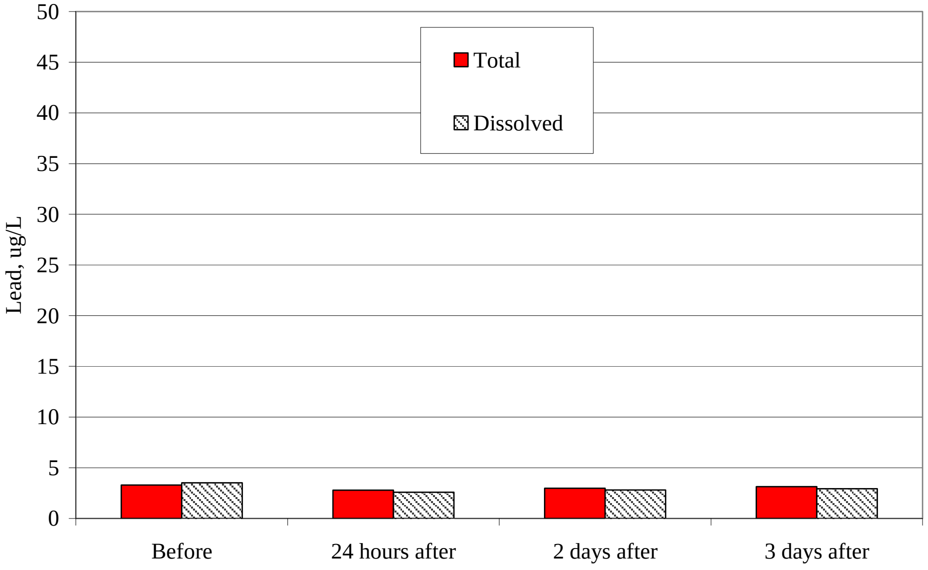


Figure F.148 Total and Dissolved Lead Levels, Flushed Samples: Site T-8

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

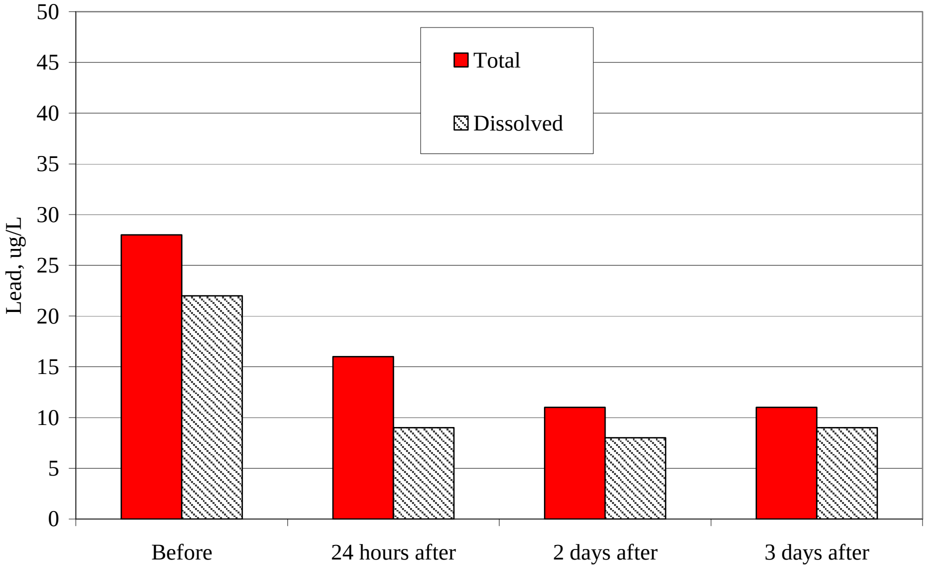


Figure F.149 Total and Dissolved Lead Levels, Flushed Samples: Site T-9

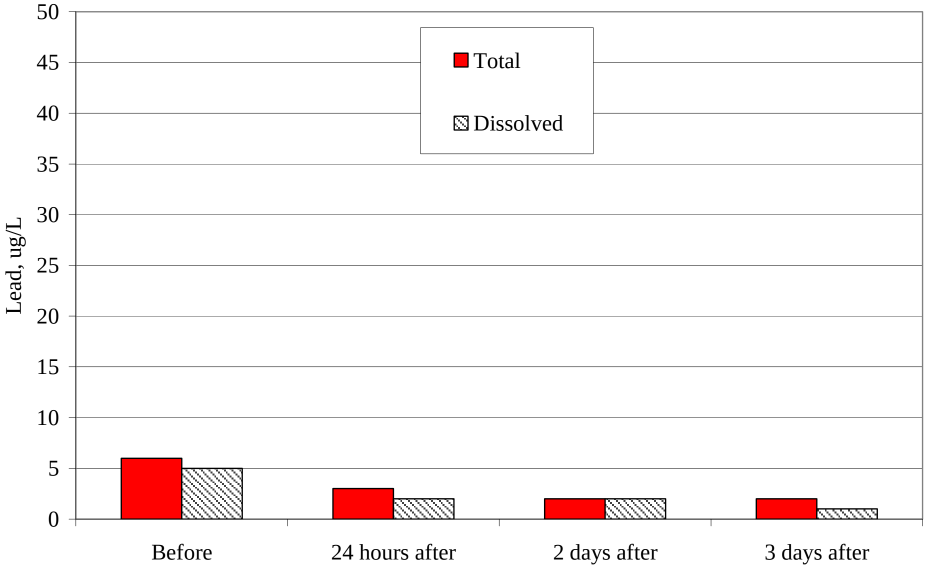


Figure F.150 Total and Dissolved Lead Levels, Flushed Samples: Site T-10

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

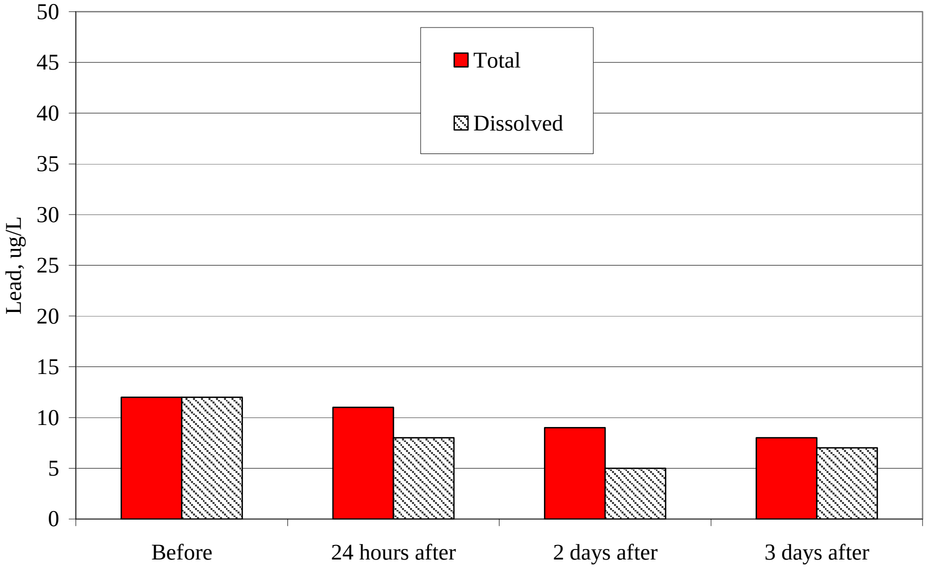


Figure F.151 Total and Dissolved Lead Levels, Flushed Samples: Site T-11

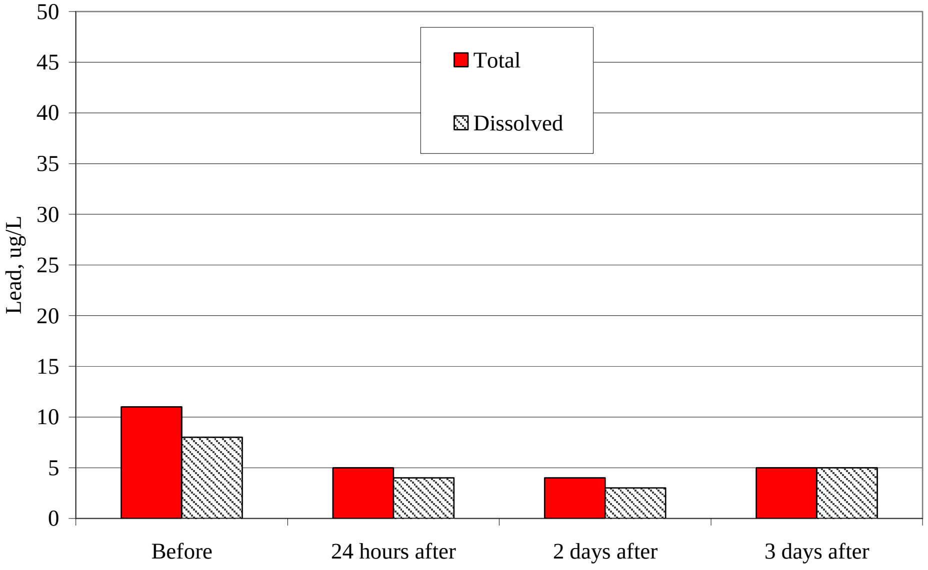


Figure F.152 Total and Dissolved Lead Levels, Flushed Samples: Site T-12

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

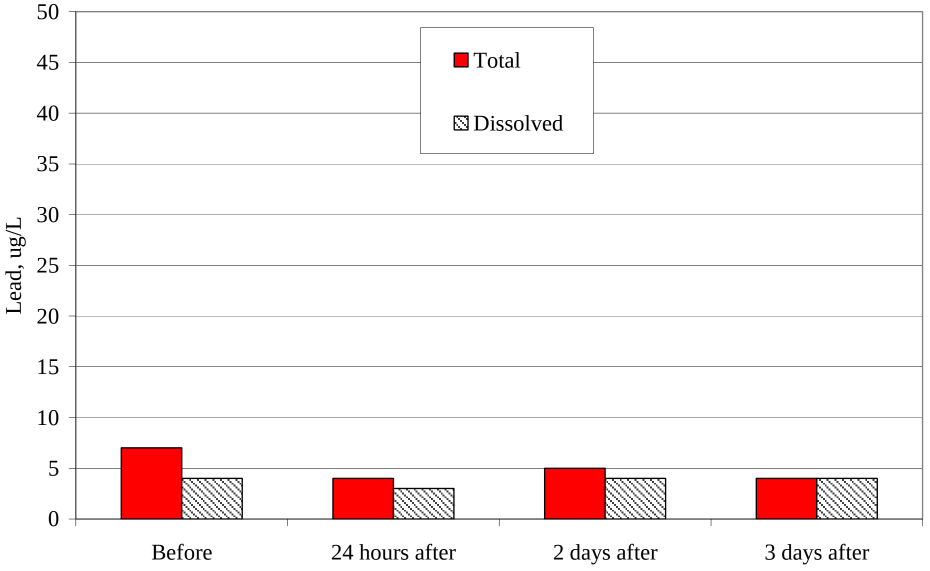


Figure F.153 Total and Dissolved Lead Levels, Flushed Samples: Site T-13

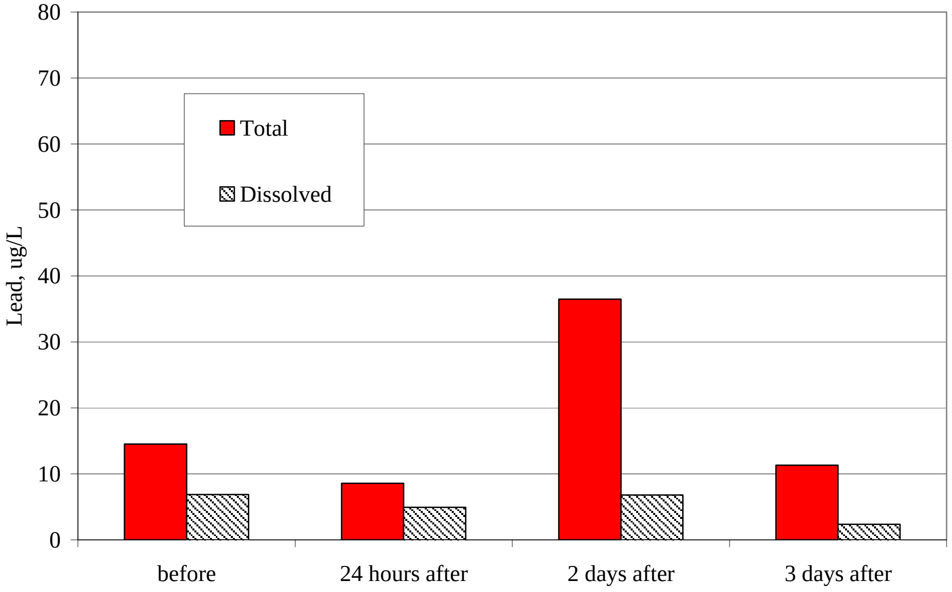


Figure F.154 Total and Dissolved Lead from Flushed Samples: SiteB-5

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

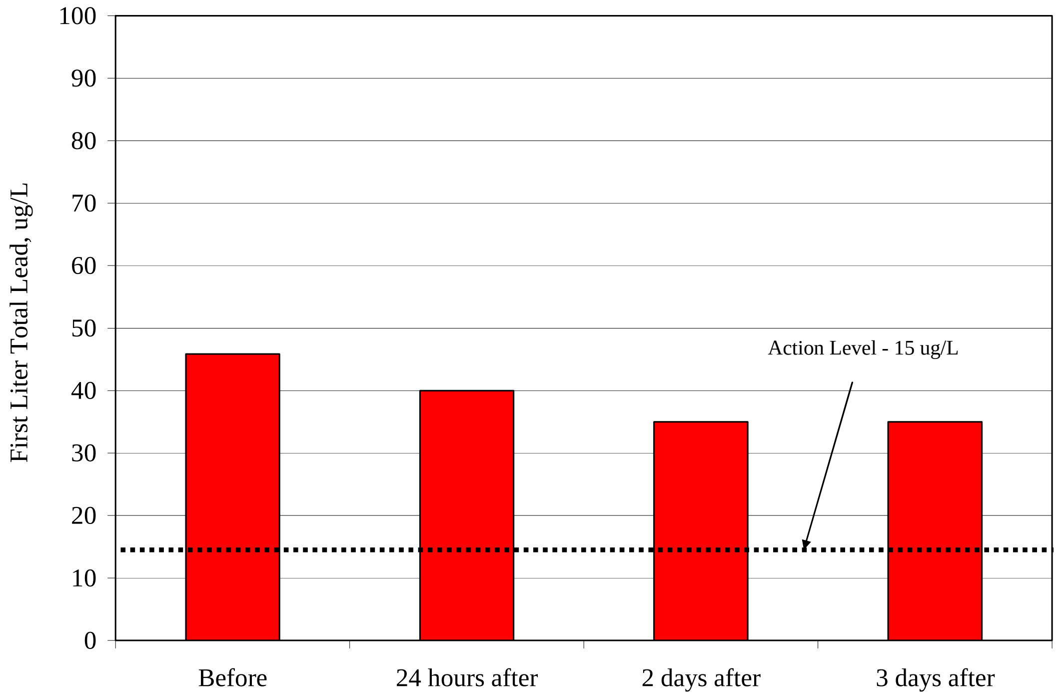


Figure F.155 First Liter Lead Level Results: Site T-5 (stagnation)

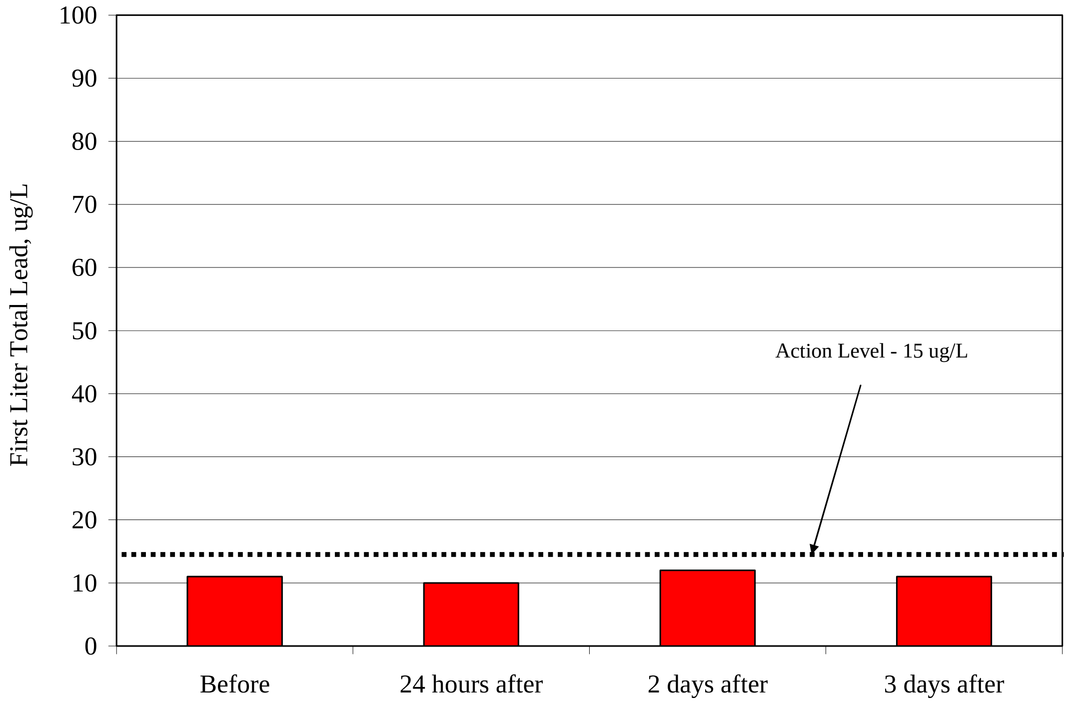


Figure F.156 First Liter Lead Level Results: Site T-6 (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

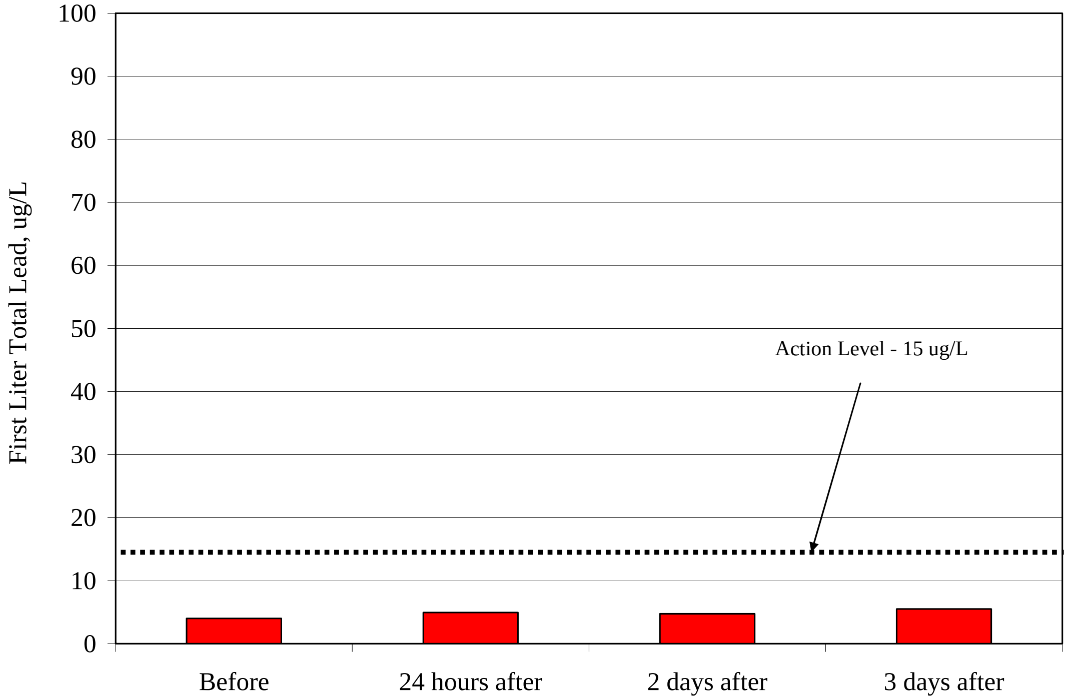


Figure F.157 Calculated First Liter Lead Level Results: Site T-7 (stagnation)

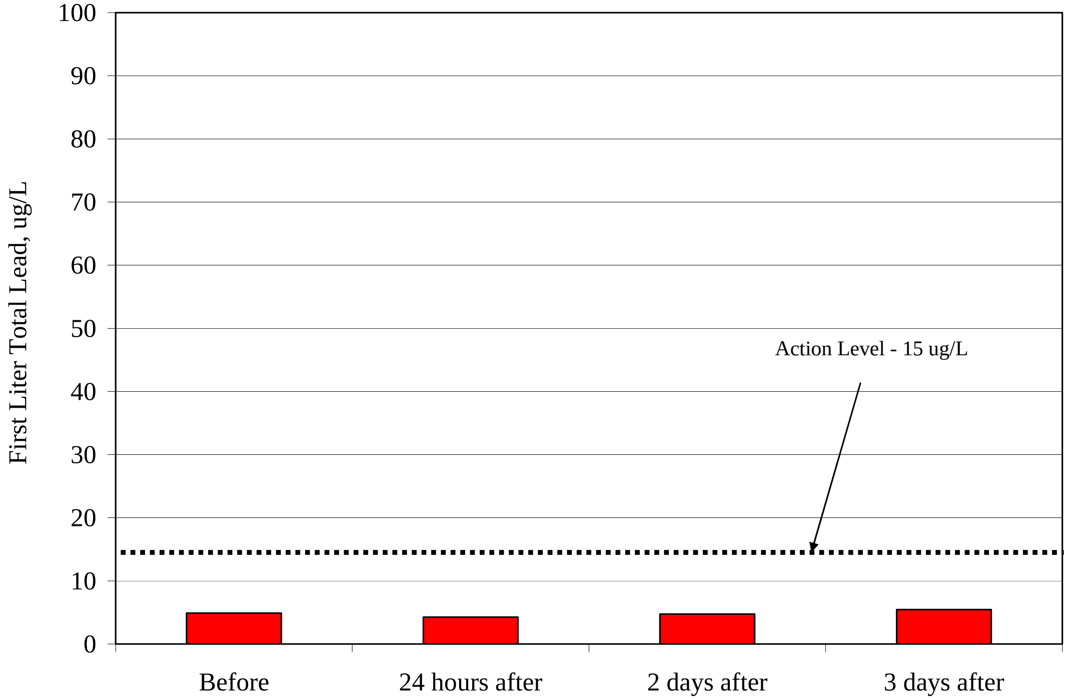


Figure F.158 Calculated First Liter Lead Level Results: Site T-8 (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

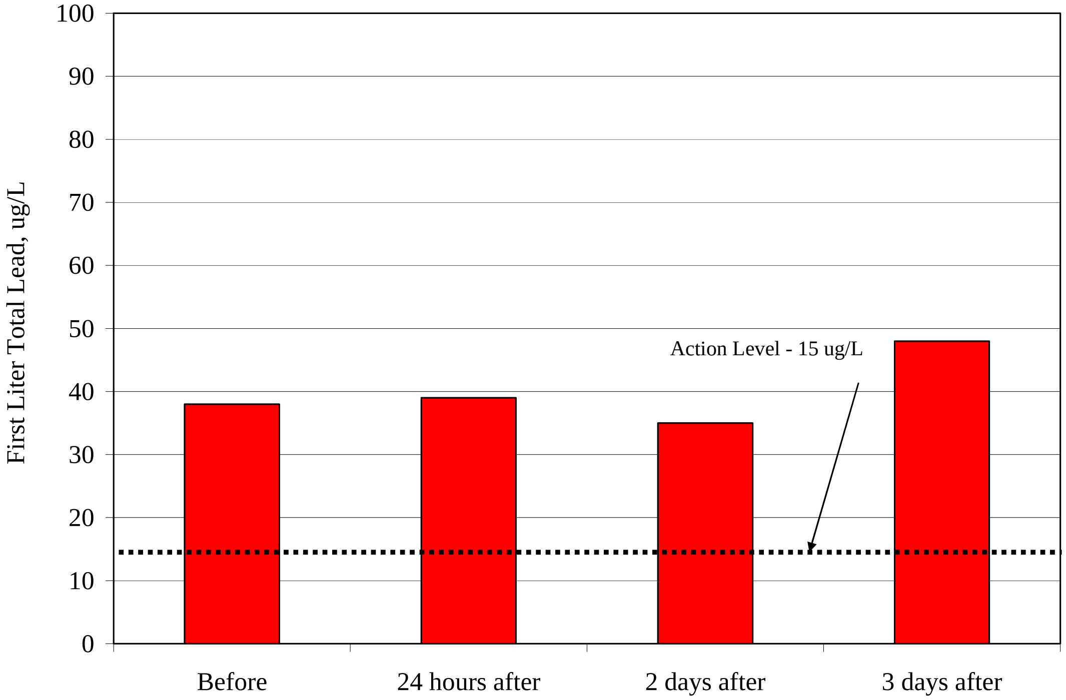


Figure F.159 Calculated First Liter Lead Level Results: Site T-9 (stagnation)

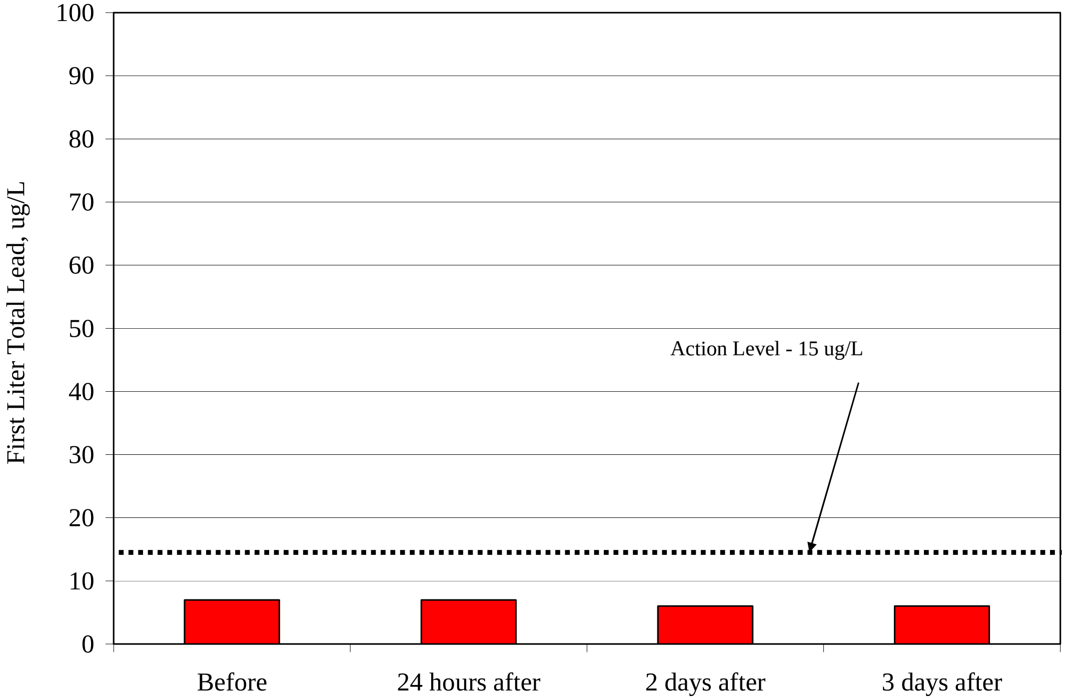


Figure F.160 First Liter Lead Level Results: Site T-10 (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

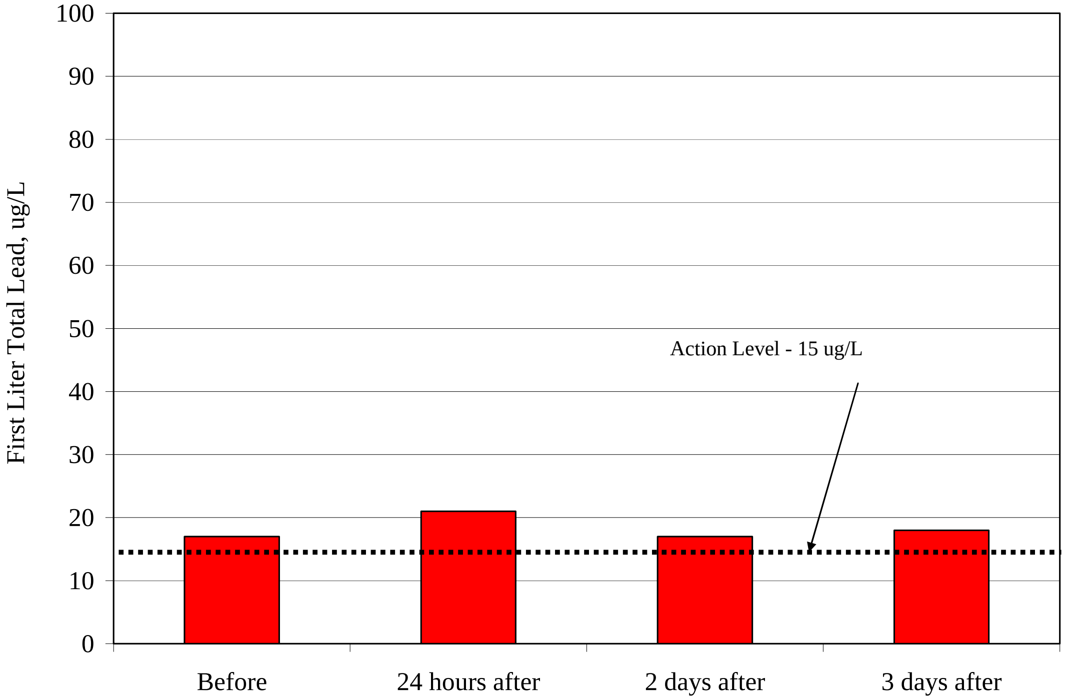


Figure F.161 First Liter Lead Level Results: Site T-11 (stagnation)

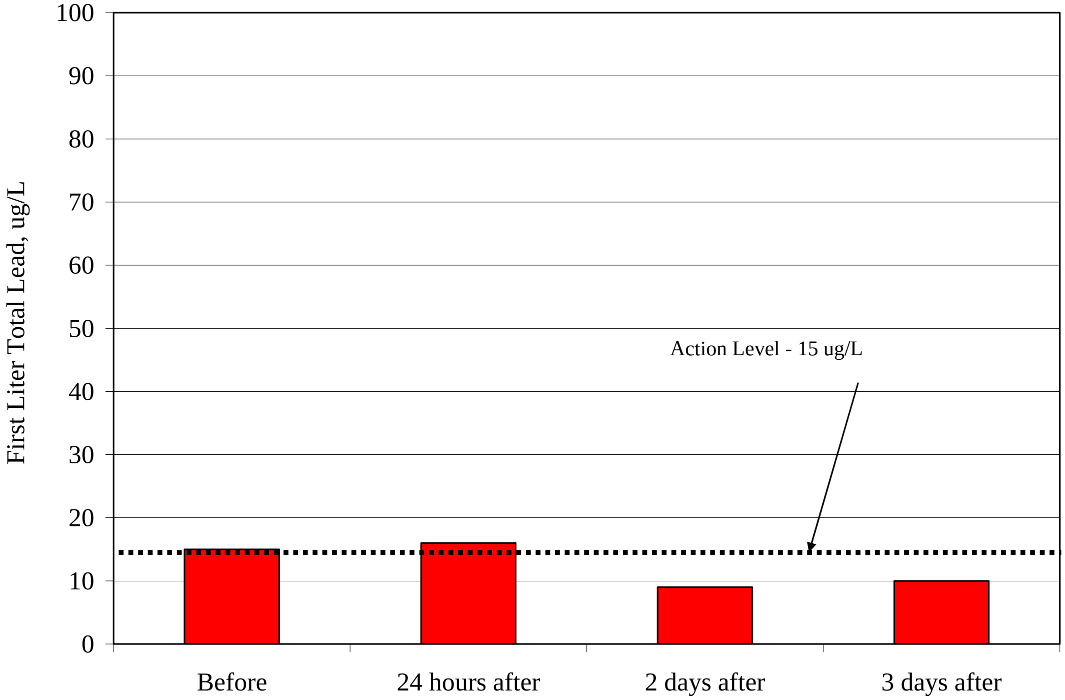


Figure F.162 First Liter Lead Level Results: Site T-12 (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

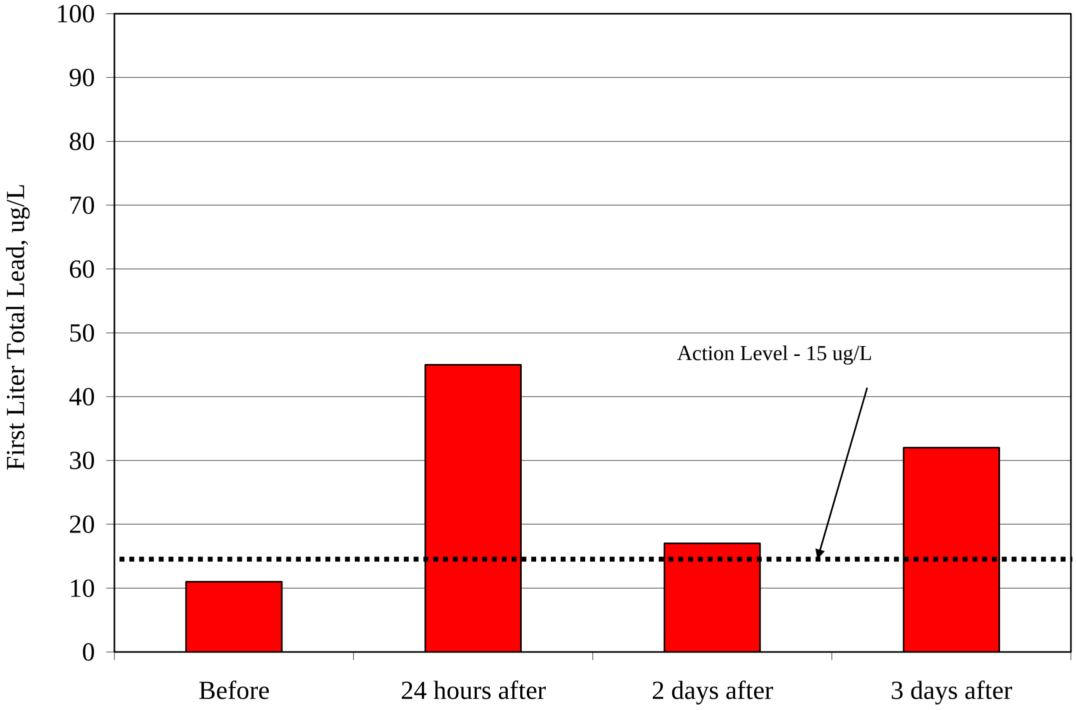


Figure F.163 First Liter Lead Level Results: Site T-13 (stagnation)

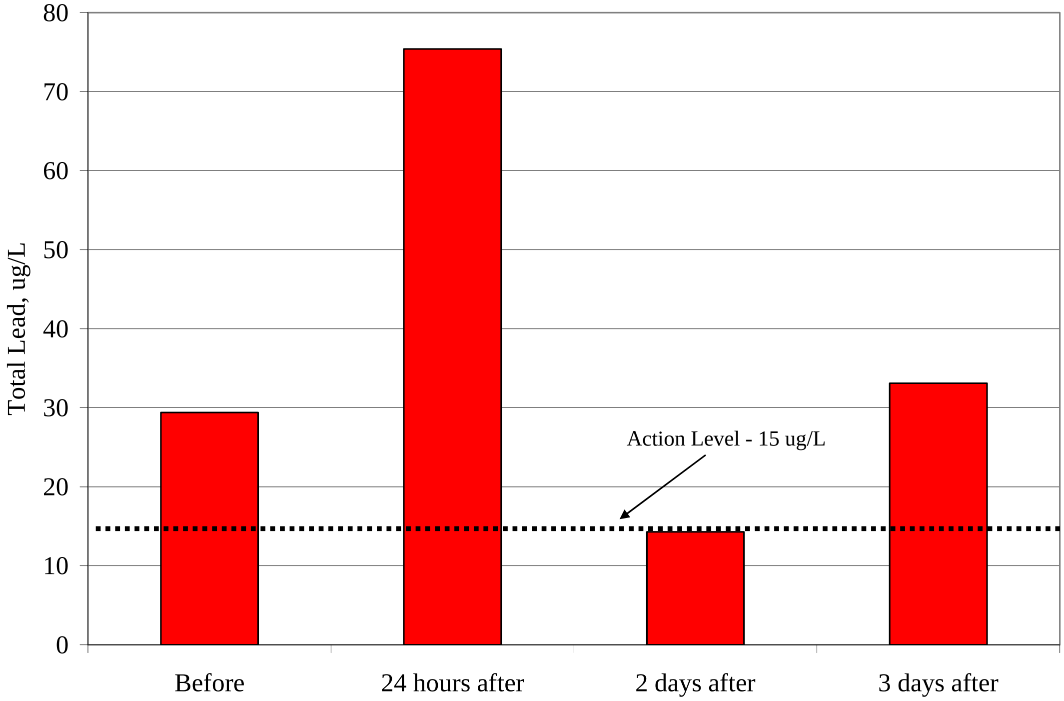


Figure F.164 Calculated First Liter Lead Level Results: Site B-5 (stagnation)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

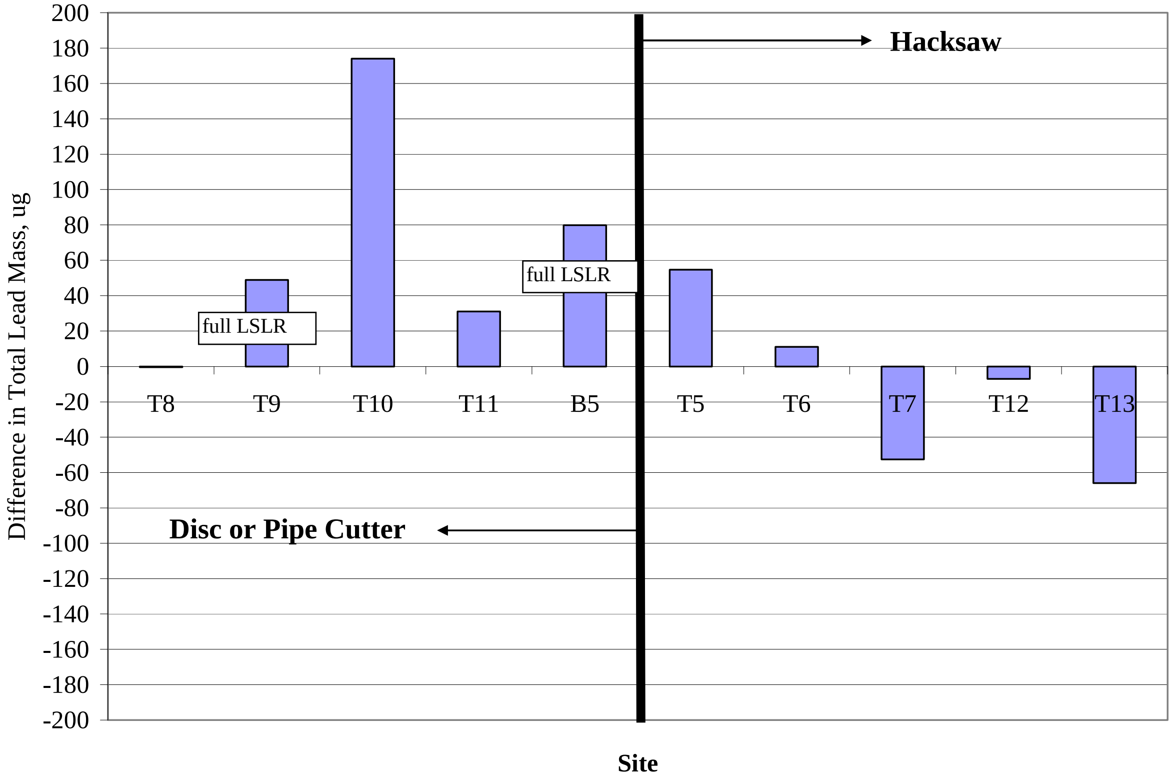


Figure F.165 Comparison of Difference in Total Lead Mass for Different Cutting Techniques

SUMMARY OF LEAD SOURCE CONTRIBUTIONS

Tables F.78 through F.86 present summaries of lead contributions calculated for each major lead source (lead service, premise piping, and lead service) from the results described above for each utility. This summarization was used to evaluate relative lead source contributions as described in Chapter 3.

Contribution of Lead Service Lines

Table F.78
Average Concentration of Lead and Lead Mass from Field Study Samples Representative of Service Lines (Before Lead Source Replacement)

Site #	Service Line Material	Samples Collected	Average Pb from Lead Service Line Samples, ug/L	Mass Pb from Lead Service Samples, ug Pb
M-1	lead	Before	34.7	104.0
M-2	lead	Before	3.7	11.2
M-3	lead	Before	31.9	95.7
M-4	lead	Before	114.4	343.1
Average			46 (4-114)	139 (11-343)
D-1	lead	Before	10.3	62.0
D-2	lead	Before	14.4	86.1
D-3	lead	Before	17.6	52.7
D-4	lead	Before	3.9	19.3
Average			12 (4-18)	55 (19-86)
B-1	lead	Before	5.9	11.9
B-2	lead	Before	22.3	67.0
B-3	lead	Before	4.3	8.6
B-4	lead	Before	18.6	37.2
Average (B1-B4)			12.7 (4-22)	31 (9 – 67)
B-5	lead	Before	62.2	62.2
Average (B1-B5)			23 (4-62)	37 (9-67)
T-1	lead	Before	19.9	79.6
T-2	lead	Before	9.2	18.4
T-3	lead/cu*	Before	10.6	31.9
T-4	lead	Before	15.6	46.7
Average (T1-T4)			13.8 (9.2 – 19.9)	44.2 (18.4 – 79.6)
F.1	lead/cu*	Before	25.4	50.5
F.2	lead	Before	28.2	169.3
Average			27 (25-28)	110 (51-169)
T-5	lead	Before	54.6	163.8
T-6	lead	Before	18.7	56.0
T-7	lead	Before	9.0	18.0
T-8	lead	Before	3.7	18.5
T-9	lead	Before	68.7	206.0
T-10	lead	Before	19.0	190.0
T-11	lead	Before	17.4	87.0
T-12	lead	Before	18.7	56.0
T-13	lead	Before	18	54.0

*Mass Pb and average Pb concentration from the lead portion of the service line

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.79
Relative % Contribution of lead service line to total mass measured during sequential sampling

Site #	Service Line Material	Samples Collected	Mass Lead Service, ug Pb	Total Mass, ug Pb	% of Total Mass from Lead Service
M-1	lead	Before	104.0	448.8	23%
M-2	lead	Before	11.2	23.2	48%
M-3	lead	Before	95.7	149.5	64%
M-4	lead	Before	343.1	555.4	62%
Average					49%
D-1	lead	Before	62.0	82.6	75%
D-2	lead	Before	86.1	127.1	68%
D-3	lead	Before	52.7	97.8	54%
D-4	lead	Before	19.3	63.1	31%
Average					57%
B-1	lead	Before	11.9	37.3	32%
B-2	lead	Before	67.0	105.5	64%
B-3	lead	Before	8.6	27.3	32%
B-4	lead	Before	37.2	58.7	63%
Average (B1-B4)					48%
T-1	lead	Before	79.6	111.6	71%
T-2	lead	Before	18.4	53.9	34%
T-3	lead/cu*	Before	31.9*	120.7	26%
T-4	lead	Before	46.7	77.0	61%
Average (T1-T4)				90.8	48%
F.1	lead/cu*	Before	50.5*	180.5*	28%
F.2	lead	Before	169.3	230.7	73%
Average				205.6	51%
T-5	lead	Before	163.8	321.7	51%
T-6	lead	Before	56.0	85.0	66%
T-7	lead	Before	18.0	22.0	82%
T-8	lead	Before	18.5	27.2	68%
T-9	lead	Before	206.0	382.0	54%
T-10	lead	Before	190.0	230.0	83%
T-11	lead	Before	87.0	121.0	72%
T-12	lead	Before	56.0	71.0	79%
T-13	lead	Before	54.0	65.0	83%
B-5	lead	Before	62.2	91.6	68%

*initial service line was lead from residence to property line and copper from property line to main

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Contribution of Premise Materials

Table F.80
Average Lead Mass and Lead Concentration from Premise Piping

Site #	Service Material	Premise piping material	Average Pb, ug/L	Mass Pb from Premise Samples, ug Pb
M-1	lead	cu	70.1	341.7
M-2	lead	cu	2.5	7.1
M-3	lead	cu	8.6	33.4
M-4	lead	cu	30.7	119.0
Average			28.0 (3 – 70)	125.3 (7 – 342)
D-1	lead	cu	5.3	15.3
D-2	lead	cu	10.1	39.1
D-3	lead	cu[1]	8.0	30.8
D-4	lead	cu[1]	8.7	42.6
Average			8.0 (5.3 – 10.1)	32.0 (15.3 – 42.6)
B-1	lead	cu/brass	6.3	18.0
B-2	lead	cu/galvanized[2]	7.4	28.8
B-3	lead	cu/galvanized[2]	5.2	15.1
B-4	lead	cu/galvanized[2]	6.8	12.7
Average (B1-B4)			6.4 (5 .2– 6.8)	18.7 (12.7-28.8)
T-1	lead	cu/PVC	10.5	19.7
T-2	lead	cu	7.4	21.2
T-3	lead/cu*	cu	11.4	44.2
T-4	lead	cu/galvanized[2]	4.3	16.8
Average (T1-T4)			8.4 (4.3-11.4)	25.5 (16.8-44.2)
F.1	lead/cu*	cu	13.7	39.4
F.2	lead	cu	21.5	43.1
Average F1-F2			17.6 (13.7-21.5)	41.3 (39.4-43.1)
H-1	Cu	cu	1.1	3.4
T-5[3]	lead	cu/galvanized[2]	49.7	99.3
T-6[3]	lead	cu	11.0	11.0
T-7[3]	lead	cu	4.0	4.0
T-8[3]	lead	cu	4.3	8.7
T-9[3]	lead	cu/galvanized[2]	44.0	176
T-10[3]	lead	cu	8.0	40.0
T-11[3]	lead	cu	17.0	17.0
T-12[3]	lead	cu/galvanized[2]	15.0	15.0
T-13[3]	lead	cu/galvanized[2]	11.0	11.0
B-5[3]	lead	cu	29.4	29.4
F.2b[4]	lead	cu	30.3	56.9

*Mass Pb a[1]nd average Pb concentration from the lead portion of the service line

[1] very small volume of PVC at kitchen faucet

[2] Percent of premise volume galvanized = B-2 (2%), B-3 (5%), B-4 (9%), T-4 (24.5%), T-9 (2.6%), T-12(15.2%), T-13 (2.7%)],

[3] First sample was one liter, so premise and faucet contribution are combined

[4] Site F.2 was resampled after the faucet was replaced, and prior to replacement of the lead service

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.81
Relative Contribution of Premise Piping

Site #	Type of Evaluation	Service Line Material	Samples Collected*	Mass Premise, ug Pb	Total Mass, ug Pb	% of Total Mass from Premise
M-1	Full LSLR	lead	Before	341.7	448.8	76%
M-2	Full LSLR	lead	Before	7.1	23.2	31%
M-3	Full LSLR	lead	Before	33.4	149.5	22%
M-4	Full LSLR	lead	Before	119.0	555.4	21%
	Average					38%
D-1	Full LSLR	lead	Before	15.3	82.6	19%
D-2	Full LSLR	lead	Before	39.1	127.1	30%
D-3	Partial LSLR	lead	Before	30.8	97.8	32%
D-4	Partial LSLR	lead	Before	42.6	63.1	68%
	Average					37%
B-1	Full LSLR	lead	Before	18.0	37.3	48%
B-2	Full LSLR	lead	Before	28.8	105.5	27%
B-3	Full LSLR	lead	Before	15.1	27.3	55%
B-4	Full LSLR	lead	Before	12.7	58.7	22%
Average (B1-B4)						38%
T-1	Full LSLR	lead	Before	19.7	111.6	18%
T-2	Full LSLR	lead	Before	21.2	53.9	39%
T-3	Partial LSLR	lead/cu	Before	44.2	120.7	37%
T-4	Partial LSLR	lead	Before	16.8	77	22%
Average (T1-T4)						29%
F.1	Faucet Replacement	lead/cu	Before	39.4	180.5*	22%
F.2	Faucet Replacement	lead	Before	43.1	230.7	19%
Average F1-F2						21%
H-1	Faucet Replacement	Cu	Before	3.4	6.1	55%
T-5	Partial LSLR	lead	Before	99.3	321.7	31%
T-6	Partial LSLR	lead	Before	11.0	85	13%
T-7	Full LSLR	lead	Before	4.0	22	18%
T-8	Partial LSLR	lead	Before	8.7	27.2	32%
T-9	Partial LSLR	lead	Before	176.0	382	46%
T-10	Partial LSLR	lead	Before	40.0	230	17%
T-11	Partial LSLR	lead	Before	17.0	121	14%
T-12	Partial LSLR	lead	Before	15.0	71	21%
T-13	Partial LSLR	lead	Before	11.0	65	17%
B-5	Full LSLR	lead	Before	29.4	91.6	32%
F.2b	LSL Replacement	lead/cu	Before	56.9	71	80%

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Faucets

Table F.82
Average Lead Mass and Average Lead Concentration from Faucets

Site #	Service Material	Premise piping material	Average Pb, ug/L	Mass Pb from Faucet Samples, ug Pb
M-1	lead	cu	24.7	3.1
M-2	lead	cu	4.4	0.6
M-3	lead	cu	13.5	1.7
M-4	lead	cu	12.2	1.5
Average			13.7 (4.4-24.7)	1.7 (0.6-3.0)
D-1	lead	cu	7.1	0.9
D-2	lead	cu	15.0	1.9
D-3	lead	cu[1]	5.3	0.7
D-4	lead	cu[1]	9.6	1.2
Average			9.3 (5.3-15.0)	1.2 (0.7-1.9)
B-1	lead	cu/brass	17.9	2.2
B-2	lead	cu/galvanized[2]	3.6	0.5
B-3	lead	cu/galvanized[2]	2.7	0.3
B-4	lead	cu/galvanized[2]	13.7	1.7
Average			9.5 (2.7-17.9)	1.2 (0.3-2.2)
T-1	lead	cu/PVC	9.2	1.2
T-2	lead	cu	6.4	0.8
T-3	lead/cu*	cu	14.9	1.9
T-4	lead	cu/galvanized[2]	15.8	2.0
	Average		11.6 (4.1-19.2)	1.5 (0.8-2.0)
F.1	lead/cu*	cu	4.1	0.5
F.2	lead	cu	19.2	2.4
Average			11.7 (4.1-19.2)	1.5 (0.5-2.4)
H-1	cu	cu	6.0	0.8
F.2b[4]	lead	cu	23.7	3.0

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.83
Relative Contribution of Faucets

Site #	Type of Evaluation	Service Line Material	Samples Collected*	Mass Faucet, ug Pb	Total Mass, ug Pb	% of Total Mass from Faucet
M-1	Full LSLR	lead	Before	3.1	448.8	0.7%
M-2	Full LSLR	lead	Before	0.6	23.2	2.4%
M-3	Full LSLR	lead	Before	1.7	149.5	1.1%
M-4	Full LSLR	lead	Before	1.5	555.4	0.3%
	Average					1.2%
D-1	Full LSLR	lead	Before	0.9	82.6	1.1%
D-2	Full LSLR	lead	Before	1.9	127.1	1.5%
D-3	Partial LSLR	lead	Before	0.7	97.8	0.7%
D-4	Partial LSLR	lead	Before	1.2	63.1	1.9%
	Average					1.3%
B-1	Full LSLR	lead	Before	2.2	37.3	6.0%
B-2	Full LSLR	lead	Before	0.5	105.5	0.4%
B-3	Full LSLR	lead	Before	0.3	27.3	1.1%
B-4	Full LSLR	lead	Before	1.7	58.7	2.9%
	Average					2.6%
T-1	Full LSLR	lead	Before	1.2	111.6	1.0%
T-2	Full LSLR	lead	Before	0.8	53.9	1.5%
T-3	Partial LSLR	lead/cu	Before	1.9	120.7	1.5%
T-4	Partial LSLR	lead	Before	2.0	77.0	2.6%
	Average					1.7%
F.1	Faucet Replacement	lead/cu	Before	0.5	180.5*	0.3%
F.2	Faucet Replacement	lead	Before	2.4	230.7	1.0%
						0.7%
H-1	Faucet Replacement	Cu	Before	0.8	6.1	12%
F.2b	LSL Replacement	Lead/cu	Before	3.0	71.0	4.2%

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Summary

Table F.84
Mass of Lead from Faucet, Premise, Service and Main – Before Lead Source Replacement

Utility	Site #	Type of Evaluation	Service Line Material	mass faucet	mass premise	mass service*	mass main
Madison	M-1	Full	lead	3.1	341.7	104	**
Madison	M-2	Full	lead	0.6	7.1	11.2	4.4
Madison	M-3	Full	lead	1.7	33.4	95.7	18.7
Madison	M-4	Full	lead	1.5	119.0	343.1	92.0
DCWASA	D-1	Full	lead	0.9	15.3	62.0	4.4
DCWASA	D-2	Full	lead	1.9	39.1	86.1	**
DCWASA	D-3	Partial	lead	0.7	30.8	52.7	13.6
DCWASA	D-4	Partial	lead	1.2	42.6	19.3	**
BWSC	B-1	Full	lead	2.2	18.0	11.9	5.2
BWSC	B-2	Full	lead	0.5	28.8	67.0	9.3
BWSC	B-3	Full	lead	0.3	15.1	8.6	3.3
BWSC	B-4	Full	lead	1.7	12.7	37.2	7.1
Toronto	T-1	Full	lead	1.2	19.7	79.6	11.2
Toronto	T-2	Full	lead	0.8	21.2	18.4	13.5
Toronto	T-3	Partial	lead/cu	1.9	44.2	31.9	**
Toronto	T-4	Partial	lead	2.0	16.8	46.7	11.5
Framingham	F.1	Faucet	lead/cu	0.5	39.4	50.5	**
Framingham	F.2	Faucet	lead	2.4	43.1	169.3	15.9
Hartford	MDC-1	Faucet	cu	0.8	3.4	1.0	1.0

*all samples from service, not just samples representative of LSL

**no samples were collected that were representative of the main

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.85
Relative Contribution – Before Lead Source Replacement

Utility	Site #	Type of Evaluation	Service Line Material	faucet	premise	service	main
Madison	M-1	Full	lead	0.7%	76%	23%	
Madison	M-2	Full	lead	2.4%	31%	48%	19.0%
Madison	M-3	Full	lead	1.1%	22%	64%	12.5%
Madison	M-4	Full	lead	0.3%	21%	61.8%	16.5%
DCWASA	D-1	Full	lead	1.1%	19%	75.1%	5.3%
DCWASA	D-2	Full	lead	1.5%	30%	66.6%	-
DCWASA	D-3	Partial	lead	0.7%	32%	53.9%	13.9%
DCWASA	D-4	Partial	lead	1.9%	68%	30.6%	-
BWSC	B-1	Full	lead	6.0%	48%	31.8%	14.0%
BWSC	B-2	Full	lead	0.4%	27%	63.5%	8.8%
BWSC	B-3	Full	lead	1.2%	55%	31.6%	12.0%
BWSC	B-4	Full	lead	2.9%	22%	63.4%	12.1%
Toronto	T-1	Full	lead	1.0%	18%	71.3%	10.0%
Toronto	T-2	Full	lead	1.5%	39%	34.1%	25.0%
Toronto	T-3	Partial	lead/cu	1.5%	37%	61.9%	0.0%
Toronto	T-4	Partial	lead	2.6%	22%	60.7%	14.9%
Framingham	F.1	Faucet	lead/cu	0.3%	22%	77.9%	-
Framingham	F.2	Faucet	lead	1.0%	19%	73%	6.9%
Hartford	H-1	Faucet	cu	12%	55%	16.3%	16.3%
Toronto	T-5	Partial	lead	-	31%	51%	18.2%
Toronto	T-6	Partial	lead	-	13%	66%	21.2%
Toronto	T-7	Full	lead	-	18%	82%	-
Toronto	T-8	Partial	lead	-	32%	68%	-
Toronto	T-9	Partial	lead	-	46%	54%	-
Toronto	T-10	Partial	lead	-	17%	83%	-
Toronto	T-11	Partial	lead	-	14%	72%	14.0%
Toronto	T-12	Partial	lead	-	21%	79%	-
Toronto	T-13	Partial	lead	-	17%	83%	-
BWSC	B-5	Full	lead	-	32%	68%	-

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table F.86

Mass of Lead from Residential Premise and Service Piping and Components Before and After Lead Source Replacement

Site #	Type of Evaluation	Service Line Material	Samples Collected*	Mass Faucet	Mass Premise	Mass Service	Mass Main	Total Mass
M-1	Full LSLR	lead	Before	3.1	342	104	27.4	448.8
M-2	Full LSLR	lead	Before	0.6	7.1	11.2	4.4	23.2
M-3	Full LSLR	lead	Before	1.7	33.4	95.7	18.7	149.5
M-4	Full LSLR	lead	Before	1.5	119.0	389.3	91.8	555.4
D-1	Full LSLR	lead	Before	0.9	15.3	62.0	4.4	82.6
D-2	Full LSLR	lead	Before	1.9	39.1	86.1		127.1
D-3	Partial LSLR	lead	Before	0.7	30.8	52.7	13.6	97.8
D-4	Partial LSLR	lead	Before	1.2	42.6	19.3		63.1
B-1	Full LSLR	lead	Before	2.2	18.0	11.9	5.2	37.3
B-2	Full LSLR	lead	Before	0.5	28.8	67.0	9.3	105.5
B-3	Full LSLR	lead	Before	0.3	15.1	8.6	3.3	27.3
B-4	Full LSLR	lead	Before	1.7	12.7	37.2	7.1	58.7
T-1	Full LSLR	lead	Before	1.2	19.7	79.6	11.2	111.6
T-2	Full LSLR	lead	Before	0.8	21.2	18.4	13.5	53.9
T-3	Partial LSLR	lead/cu	Before	1.9	44.2	74.7		120.8
T-4	Partial LSLR	lead	Before	2.0	16.8	46.7	11.5	77.0
F.1	Faucet Replacement	lead/cu	Before	0.5	39.4	140.6		180.5
F.2	Faucet Replacement	lead	Before	2.4	43.1	169.3	15.9	230.7
H-1	Faucet Replacement	cu	Before	0.8	3.4	1	1.0	6.2
M-1	Full LSLR	cu	2 months		25.1	11.3	-	36.4
M-2	Full LSLR	cu	2 months		4.1	3.1	1.0	8.2
M-3	Full LSLR	cu	2 months		3.7	3.0	-	6.7
M-4	Full LSLR	cu	2 months		9.3	2.0	-	11.3
D-1	Full LSLR	cu	2 months		16.8	15.8	1.1	33.7
D-2	Full LSLR	cu	2 months		7.1	4.3	0.7	12.1
D-3	Partial LSLR	lead/cu	2 months		34.3	38.4	10.2	82.9
D-4	Partial LSLR	lead/cu	2 months		271.5	302.3	3.9	577.7
B-1	Full LSLR	cu	2 months	0.24	3.5	2.4	3.6	9.7
B-2	Full LSLR	cu	2 months	0.6	5.4	5.5	2.4	13.8
B-3	Full LSLR	cu	2 months	0.3	14.9	8.2	1.4	24.8
B-4	Full LSLR	cu	2 months	0.3	8.3	9.8	2.0	20.3
T-1	Full LSLR	cu	2 months	0.7	17.6	38.3	3.3	59.9
T-2	Full LSLR	cu	2 months	0.5	4.1	10.0	4.0	18.6
T-3	Partial LSLR**	cu	2 months	0.6	9.5	7.0	-	17.1
T-4	Partial LSLR	lead/cu	2 months	1.4	14.6	39.0	8.0	63.0
F.1	Faucet Replacement	lead/cu	1 month	1.6	8.8	-	-	10.4
F.2	Faucet Replacement	lead	1 month	3.7	28.2	-	-	31.9
H-1	Faucet Replacement	cu	1 month	0.4	2.9	-	-	3.3

* Samples collected before LSLR or faucet replacement, and 1 or 2 months after replacement

** Customer owned service was copper, utilities was lead before replacement. After replacement, entire line was copper.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

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APPENDIX G

SCALE ANALYSIS PROCEDURES FOR PIPING SPECIMENS

INTRODUCTION

To provide a more complete understanding of the interrelationships between water quality and the mineralogical scales that build up on the interior of water distribution and premise piping, characterizations of scales from piping and components specimens from various distribution systems were completed. Scale analyses were completed on material specimens removed from the service line and premise piping of residential sampling sites at several utility locations, and from the pilot rigs at the Portland Water Bureau, Seattle Public Utilities, and the Washington Aqueduct. A comparison and evaluation of these results with respect to the water quality and treatment practices of the utilities where these specimens were obtained was prepared.

This appendix presents the objectives of the scale analyses completed for this project, describes the methodology for evaluation, and presents a guide to procedures that can be used when analyzing scales from piping and components.

OBJECTIVE

The objectives for scale analyses were as follows:

- To characterize the elemental and mineralogical content of interior scales on lead service piping, brass connective fittings, valves, or meters, and brass faucets removed from various water distribution systems
- To correlate the elemental and mineralogical content of these interior scales to distributed water quality conditions, and
- To relate, where possible, the stratigraphic distribution of mineral layers within the scales to the history of water treatment changes.

METHODS AND MATERIALS

Collection, Shipping, and Handling

There were three types of material specimens that were collected for this project: kitchen faucets, lead service pipe, lead service pipe with gooseneck connections to brass, galvanized premise piping, brass premise piping, and brass meters.

Existing kitchen faucets and meters were removed with care taken to not damage the interior in contact with water. After removal, they were drained of any remaining water by gravity. The ends were plugged with rubber stoppers secured with duct tape and packed securely for shipment to the University of Cincinnati (UC). The lead service pipe specimens were separated from the rest of the removed lead service line (LSL) using a pipe cutter or saw. Once separated, each section of the pipe specimen was drained and labeled to indicate the sample site, flow direction, and up/down orientation of the pipe when it was in service. Each section was kept damp with the ends plugged and packed securely for shipment to UC and kept sealed for up to a week before the pipe was scraped. All specimens were shipped via overnight express service.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Analytical Procedures

Analyses of the material specimens consisted of visual and photographic observations and analysis of samples of scale removed from the interior surfaces. Analyses completed included initial inspection and photography, x-ray diffraction, raman spectroscopy, x-ray fluorescence, and scanning electron microscopy (SDM) with energy dispersive spectroscopy (EDS). Figure G.1 presents a visual summary of these analytical techniques. In addition, Figures G.2a and G.2b provide visual examples of some of the more common minerals that may comprise scales in potable water distribution systems.

Summary of Analytical Techniques Employed

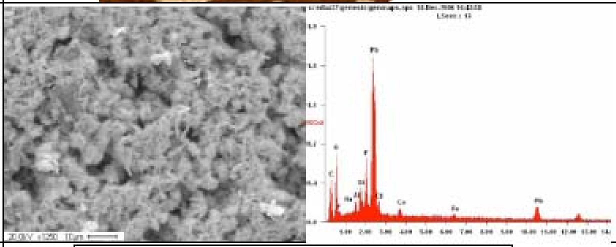
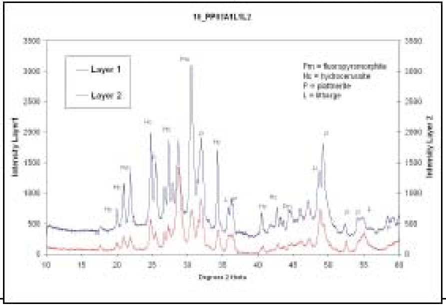
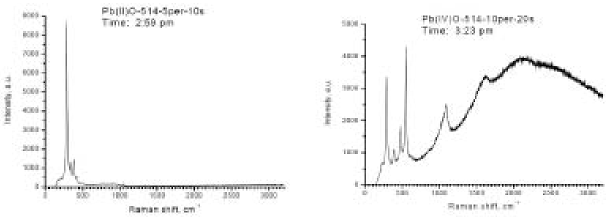
Method	Illustration	Comment
Light Microscopy		Surface of lead pipe covered with an adherent scale of cerrusite (white) and a loose scale of Platnerite (rust color) This method allows the observer to record the physical appearance of the deposit
Environmental scanning electron microscopy and energy dispersive xray analysis of x-rays (EDAX)		Surface of lead pipe covered with needle-shaped crystals of pyromorphite (a form of lead phosphate). ESEM photo-micrographs allow high resolution observation at a very small scale. The associated EDAX (done with the same instrument) allows confirmation of the general elemental abundance in the deposit.
X-ray Difraction (XRD)		Top layer of deposit on lead pipe in blue (Pyromorphite>>Plattnerite>hydrocerussite~cerussite~litharge) Second layer of same deposit in red (Litharge>pyromorphite>hydrocerussite>plattnerite>crussite) Technique alows identification of crystalline make-up of deposits. Does not identify amorphous deposits.
Laser Raman Spectroscopy		Spectra of deposits on two different lead pipes Left deposit of lead in the Pb(II) state Right - deposit of lead in the Pbv(IV) state Allows confirmation of distinctions between Pb(II) and Pb(IV)

Figure G.1 Summary of Analytical Techniques

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Common lead minerals found as corrosion products in drinking water distribution systems

Name (in order of decreasing solubility)	**Formula**	**Solubility at 15°C, pH = 7.5**	**Mineral specimen image** (www.mindat.com)	**Pipe scale image** (1)
Litharge	PbO	772.7		
Plattnerite	PbO_2	19.85		
Hydrocerussite	$Pb_3(CO_3)_2(OH)_2$	0.327		
Cerussite	$PbCO_3$	0.249		
Pyromorphite	$Pb_5\,(PO_4)_3\,X$ $X = Cl, F, OH$	0.0337		

1)Solubility in moles/L x 10^{-6} from PHREEQC model of Toronto drinking water
2)Figures from Mike DeSantis, Geologist,Pegasus Technical Services, Inc. and Michael Schock, USEPA

Figure G.2a Common Lead Minerals

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Name	Chemistry	Appearance
Calcite	$CaCO_3$	
Aragonite	$CaCO_3$	
Vaterite	$CaCO_3$	

Figure G.2b Common Calcium Carbonate Minerals

GUIDE TO SCALE ANALYSIS PROCEDURES

Sample receipt and initial preparation

Pipe samples should be given a laboratory numbers that contains a city code, a fixture code, and a materials code. City codes are 01, 02, 03, etc.

Fixture codes are

P	pipe
F	faucet
M	meter
V	valve

Materials codes are

P	lead
C	copper
B	brass
F	iron
X	mixed

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Thus if the first sample from utility 2 is a segment of lead pipe, it would receive the designation 02_PP01. A second segment of lead pipe attached to a brass fitting would be 02_PXP02, whereas the matching brass segment would be 02_PXB02 and a brass valve connected to this pipe segment would be 02_VB03 (Figure G.3).

Next pipe segments need to be cleaned on the outside. Stoppers are inserted in each end of the pipe and the outside surface washed to remove loose mud. For lead pipes, the cleaned pipe is then split in half lengthwise using a band saw. One half is designated as A and is used to remove scale for analysis, whereas the B half is retained for photography and as a reference. For pipes longer that ~ 50 cm, the pipe is cut into several shorter segments. Starting from the end closest to the water main, if known, each segment receives an additional label, as shown in Figure G.4.

Brass valves can be handled in the same manner. For faucets and meters, they must first be disassembled far as possible, and the non-wetted parts set aside. Then the wetted parts can be numbered as 05_FB01valvebody, 05_FB01coldsupply, etc.

Initial inspection and photography

Once cut open, the samples are inspected and the distribution of scale textures and colors described and recorded photographically. The scales on both lead and brass pipes will typically vary over the area of the sample.

Macrophotographs (using a light stand) and photomicrographs (using a binocular microscope with up to 50x magnification) are needed (Figures G.5 and G.6). Because the pipes are curved, good focus is hard to achieve at higher magnifications.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

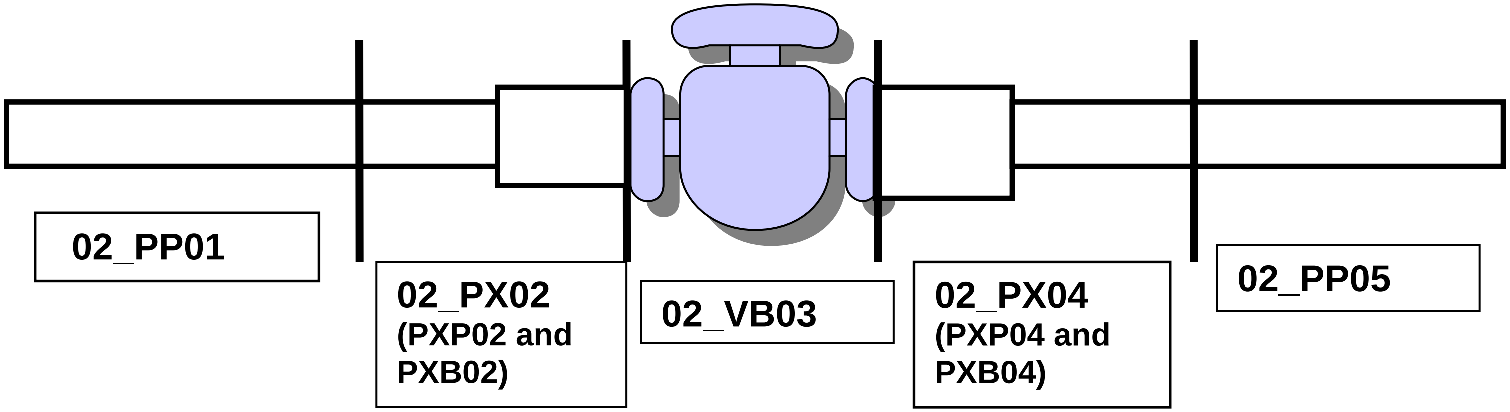


Figure G.3

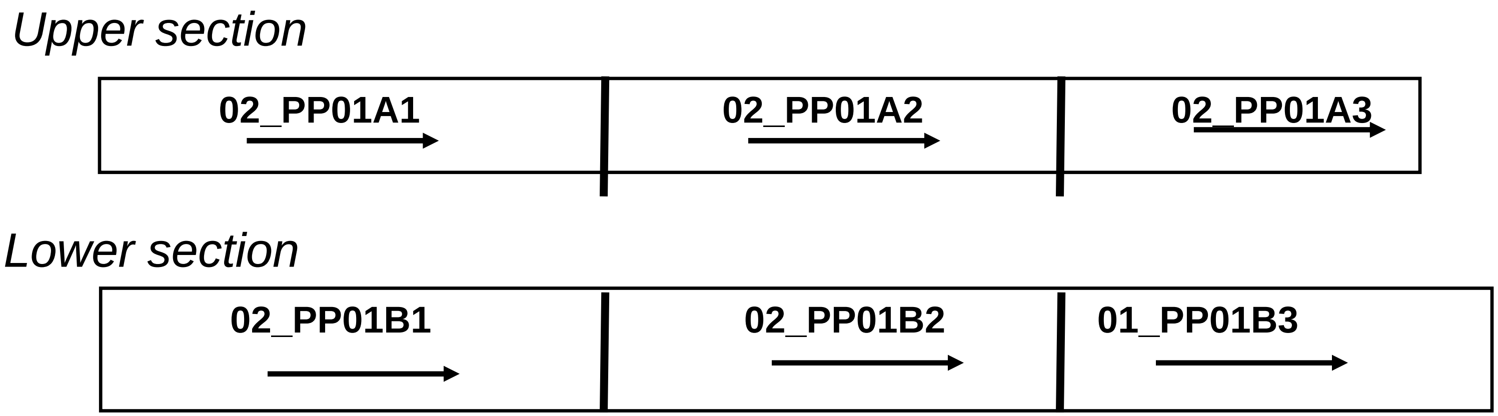


Figure G.4

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

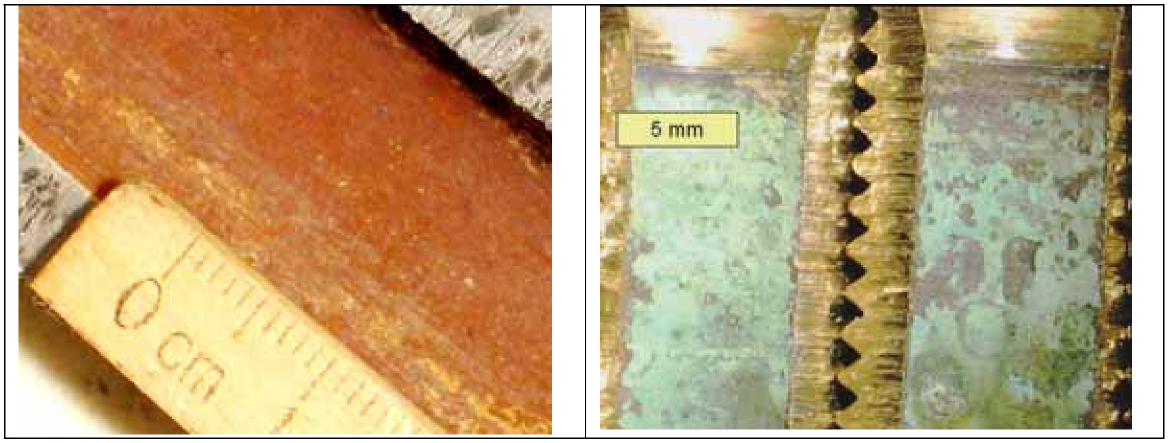


Figure G.5 Macrophotographs of split segment of lead (left) and brass (right) pipes

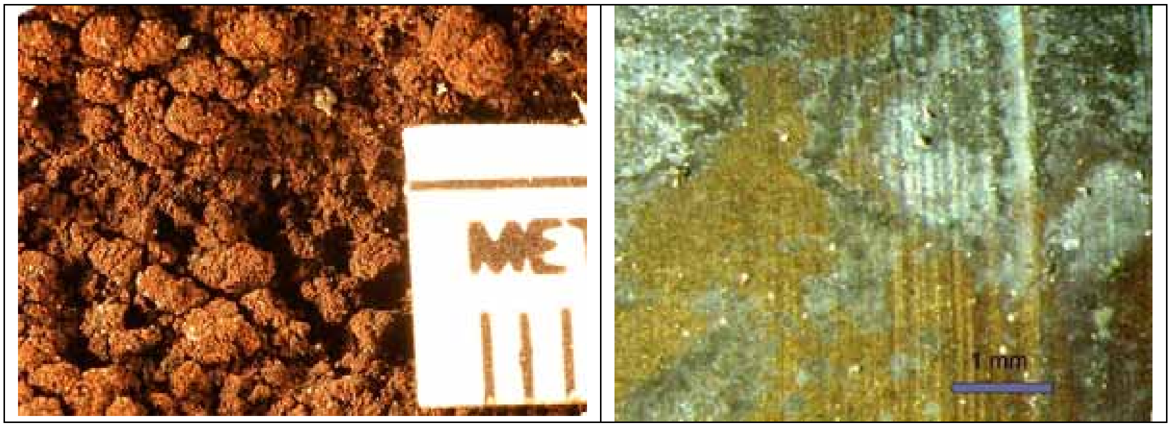


Figure G.6 Photomicrographs showing irregular Mn-rich surface layer on Pb pipe scale (left) and incomplete coverage of brass by copper carbonate scale on a brass faucet (right).

Mineralogy by x-ray diffraction.

The most important scale characterization tool is x-ray diffraction (XRD) because it reveals the mineralogy of the dominant scale solids. For pipes that have reacted for many years, there will generally be sufficient scale for it to be scraped off sequentially to yield two or three operationally-defined layers that can then be analyzed by traditional powder diffraction methods. A zero-background plate can be used to reduce noise in the spectrum. The mineralogy determined can then be compared to the water chemistry to predict future reactions. Good diffraction records can be achieved with Cu K radiation with the following conditions:

- High precision scan: 10 hours 5 to 75 $^{o}2\theta$, 0.01^{o} step size, 5 sec per step
- Rapid scan: 3 hours 10 to 60 $^{o}2\theta$, 0.02^{o} step size, 4 sec per step

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

The high-precision scan is conveniently run overnight. If machine time is limited, the rapid scan can be substituted, but the identification of minor phases and the estimate of relative mineral abundances is less reliable. Figure G.7 is an XRD pattern from a lead sample.

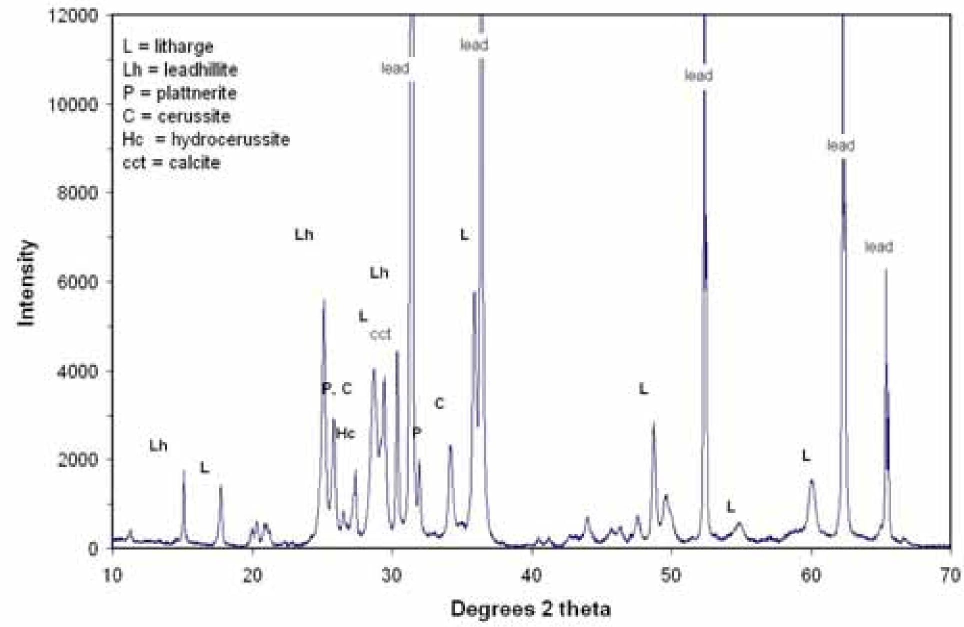


Figure G.7 XRD pattern from a lead sample. This sample is from an early stage of reaction and an unusually large variety of minerals are present, plus reflections from the underlying metal are very strong. A blank spectrum using a cleaned and polished pipe sample can be subtracted from this pattern to remove the lead metal peaks.

An estimate of relative abundance of the mineral phases can be obtained from the peak heights of the diffraction pattern. The largest peak, in this case the one for leadhillite at about 25 degrees, is assigned a value of 100. Then the peak height of the strongest peak for each of the other minerals is given as a percentage of the height of this peak.

Mineralogy by Raman scattering

Raman spectroscopy is not employed as often as XRD in corrosion studies, but it is a valuable complementary technique because it can detect poorly-crystalline phases and it provides confirmation of identifications made by XRD for minerals with closely-overlapping patterns. The technique is widely used for characterization of art works and a variety of tools are available for widely varying prices. Figure G.8 presents a raman spectrum for a pipe containing lead carbonates.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

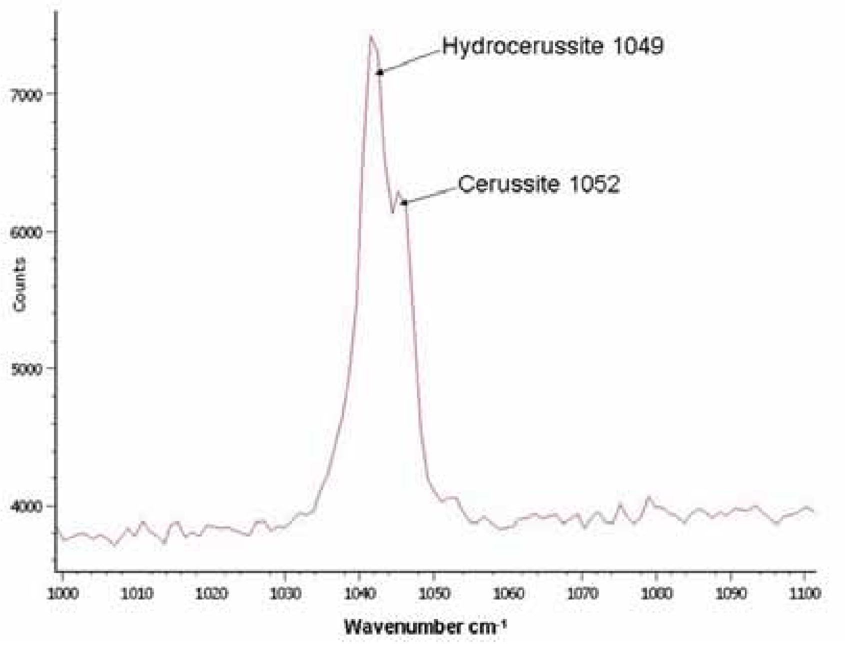


Figure G.8 Raman spectrum from a pipe scale dominated by Pb carbonates.

Chemistry by x-ray fluorescence

The scraped samples used for XRD analysis can be recovered and used in x-ray fluorescence (XRF) for bulk chemistry determinations. Normally this technique uses 2-3 grams of material, so the method was adapted for smaller sample volumes.

Two hundred fifty (250) mg of sample powder, fine enough to pass a 200 mesh stainless steel sieve, is mixed with spectroscopic grade cellulose powder to make a total weight of 2.5 grams. The sample mixture is then homogenized by shaking in a ball mill using two polyacrylate balls. The resulting powder is then pressed into a standard XRF pellet. A series of standards is prepared using the same procedure. Note that some barium (Ba) peaks are severely overlapped by minor copper (Cu) peaks. The strong Cu radiation coming from a brass scale may give a high Ba blank for some analytical lines. Other elements may have lesser interferences, so it is essential to run a blank using a copper oxide standard.

Microanalysis by SEM_EDS

Additional insight into scale chemistry can be obtained by using scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS). This approach extends to much higher magnification than light microscopy and can be used to study reaction sequences and, in some cases, to identify biological components of the scale. The energy dispersive analysis gives information about spatial distribution of chemical elements in the scale. Figures G.9 and G.10 are examples of SEM and EDS patterns for lead carbonate and lead oxide.

Sample preparation involves simply removing a very small amount of scale with an exacto knife blade and transferring to an SEM stub with carbon mounting tape. The sample is then coated with gold-paladium to prevent charge buildup.

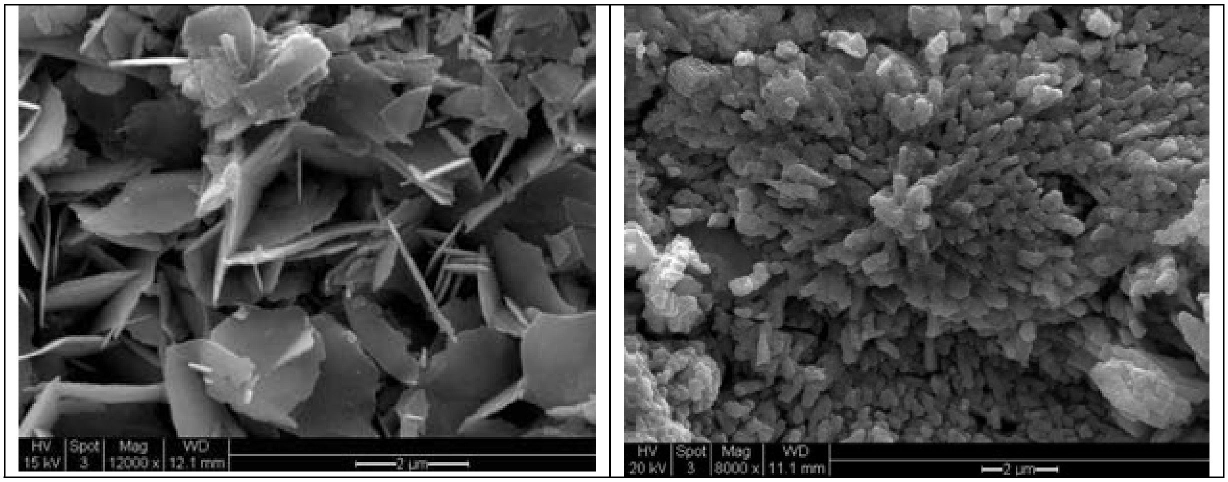


Figure G.9 Examples of scanning images of Pb carbonate (left) and Pb oxide (right). The similarity in elemental compositions of the carbonate varieties cerussite and hydrocerrusite make them difficult to distinguish by EDS, but hydrocerussite commonly occurs in the hexagonal plates shown, whereas cerussite tends to make prismatic crystals more tightly bunched. The Pb oxides litharge and plattnerite are similarly difficult to distinguish, but plattnerite is usually finer grained.

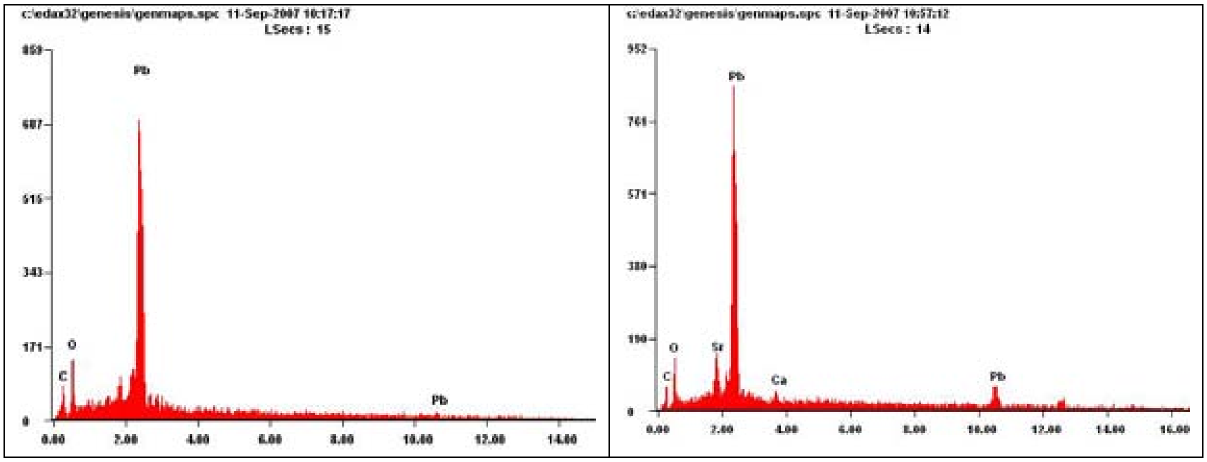


Figure G.10 Examples of EDS patterns of the Pb carbonate (left) and Pb oxide (right). Unlabelled peaks are from the Au-Pd coating. Note the presence of some Ca and Sr in the Pb oxide pattern. They suggest the presence of some calcite in addition to plattnerite.

Images should be made in both the scanning and the back-scatter mode. Back-scatter intensity is proportional to Z, the average atomic weight of the elements present, and is very sensitive to small variations in composition. It is a valuable mapping tool for finding compositional differences. Figure G.11 displays SEM images using both scanning mode and backscatter mode.

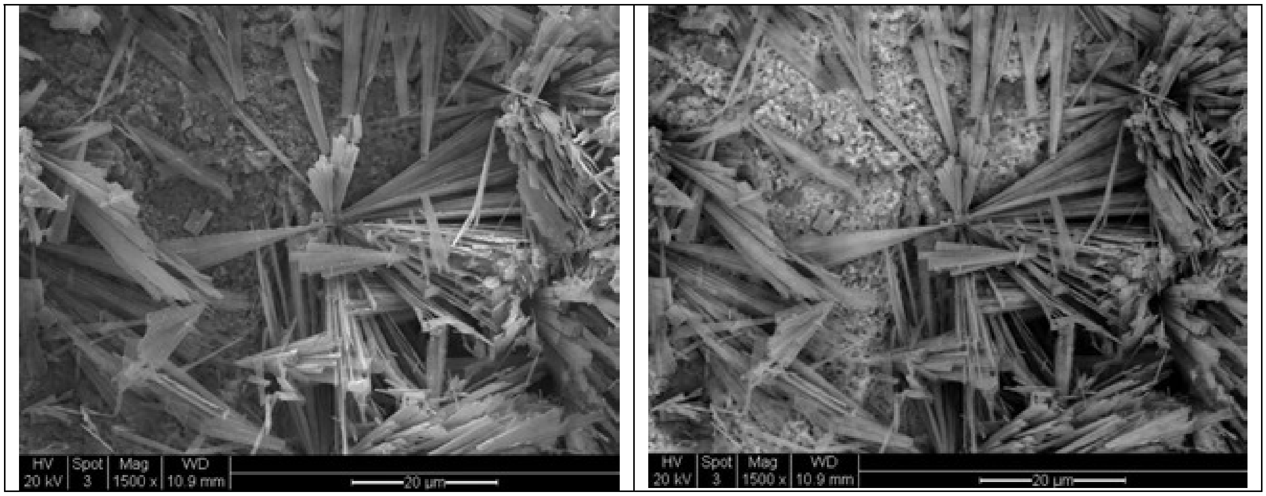


Figure G.11 Two ways of imaging in the SEM are scanning mode, left, and backscatter mode, right. Scanning is a direct image, whereas backscatter intensity is a function of atomic weight of the atoms in a mineral. The needles in these views are Cu carbonate, whereas the fine, granular material with slightly higher BSE intensity is Cu oxide.

On occasion, biological structures are revealed in the SEM. Most bacteria are too small for effective imaging, but filamentous forms are distinctive, as are diatoms (Figure G.12).

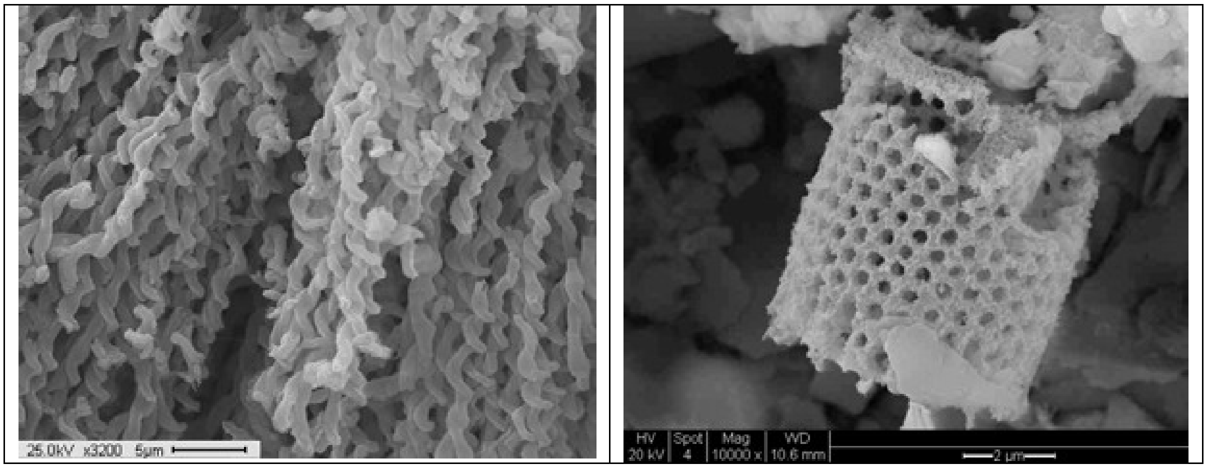


Figure G.12 Biological scale components. Right: filamentous Fe oxidizing bacteria. Left: siliceous skeleton of a diatom.

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

APPENDIX H

DCWASA LEAD PROFILES

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

INTRODUCTION

DCWASA conducted lead profile sampling at numerous sites within their service area from December 2004 through January 2007. These profiles were made available for this study, and are displayed in this appendix. At each site, an initial sample was collected in the morning after high water use, followed by a 6 to 8 hour stagnation period after which sequential 1 liter samples were collected at the tap. Total and dissolved lead was analyzed on all samples. Figure H.1 through H.8 display the total lead level results for these profiles. Figures H.1 through H. 4 display lead profile data collected prior to implementation of orthophosphate treatment for corrosion control. Figures H.5 through H.8 were collected after orthophosphate treatment was installed.

For each profile, information on which samples corresponded to premise piping versus service piping were provided. Table H.1 lists the average total lead concentrations for samples representative of premise piping and samples representative of service piping from these profiles. Average lead levels were lower after use of orthophosphate, both for premise piping and for service piping. Prior to use of orthophosphate, the average lead concentration from service piping was more than twice the concentration from premise piping. After orthophosphate treatment, the average lead concentration from premise and service piping was similar.

Table H.1
Average Total Lead Concentrations from DCWASA Profiles

	Premise Piping	Service Piping
	Profiles collected in 2003 – 2004 (no PO4)	
No. of Samples	50	57
Average, ug/L	20.7	58
Median, ug/L	18.6	48
Min-Max, ug/L	2.3 - 57	0.9 - 250
	Profiles collected in 2004 – 2007 (PO4)	
No. of Samples	42	82
Average, ug/L	10.1	8.4
Median, ug/L	7.1	5.0
Min-Max, ug/L	0 – 50	0 - 34

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

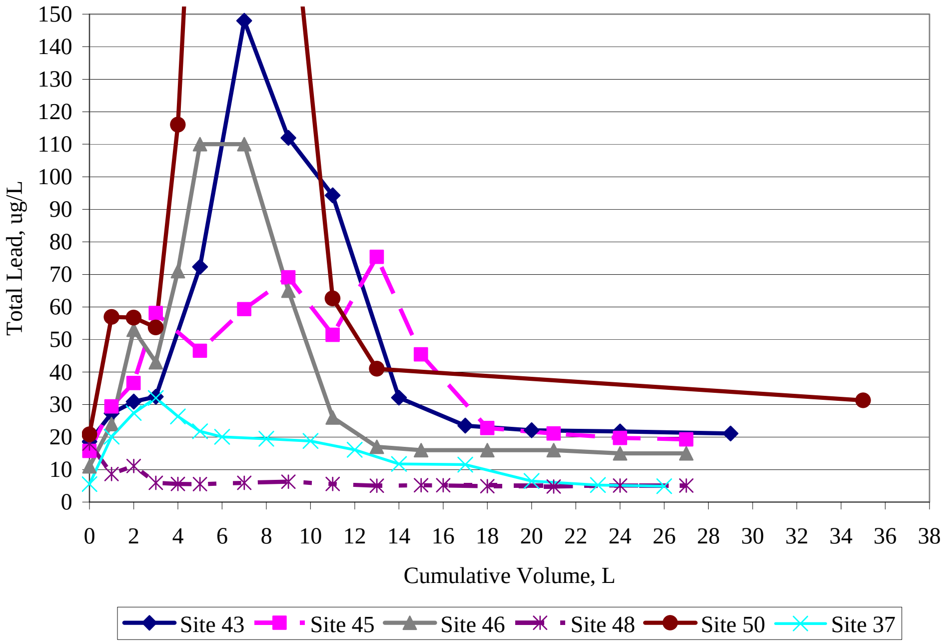


Figure H.1 Lead Profiles from Sites 37, 43, 45, 46, 48, and 50 (Collected in 2003 and 2004 – no PO4)

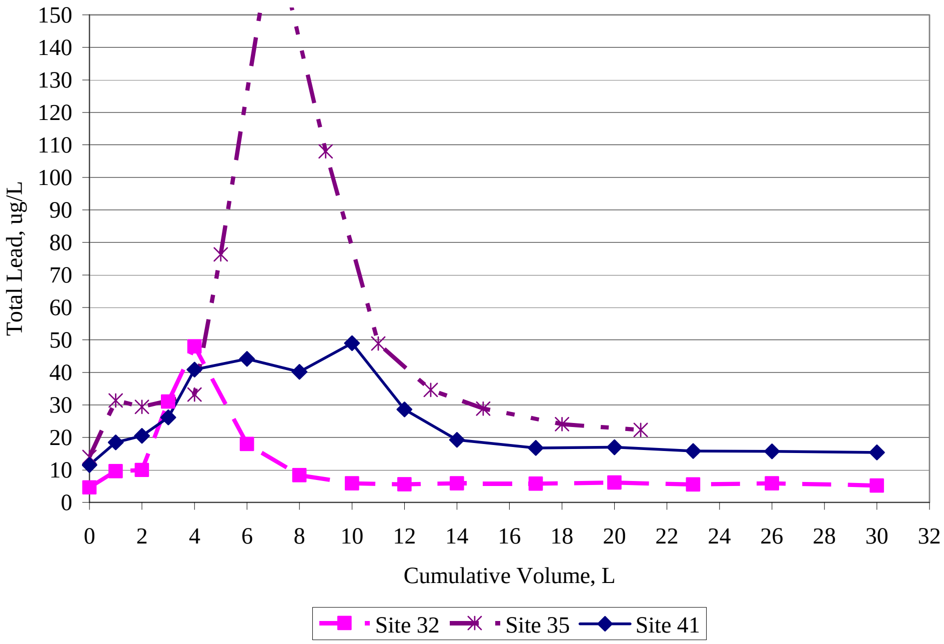


Figure H.2 Lead Profiles from Sites 32, 35, and 41 (Collected in 2004 – no PO4)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

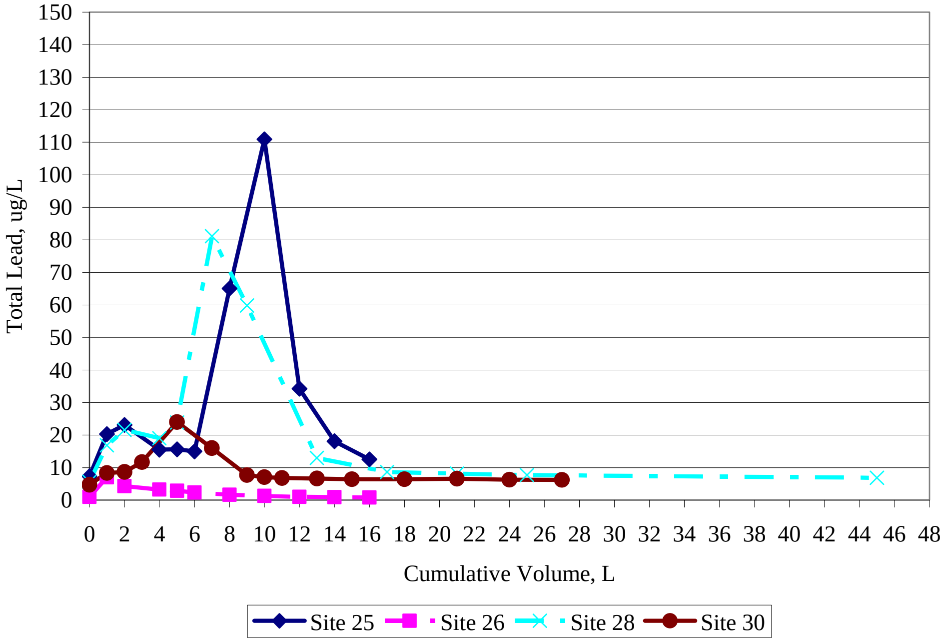


Figure H.3 Lead Profiles from Sites 25, 26, 28 and 30 (Collected in 2004 – no PO4)

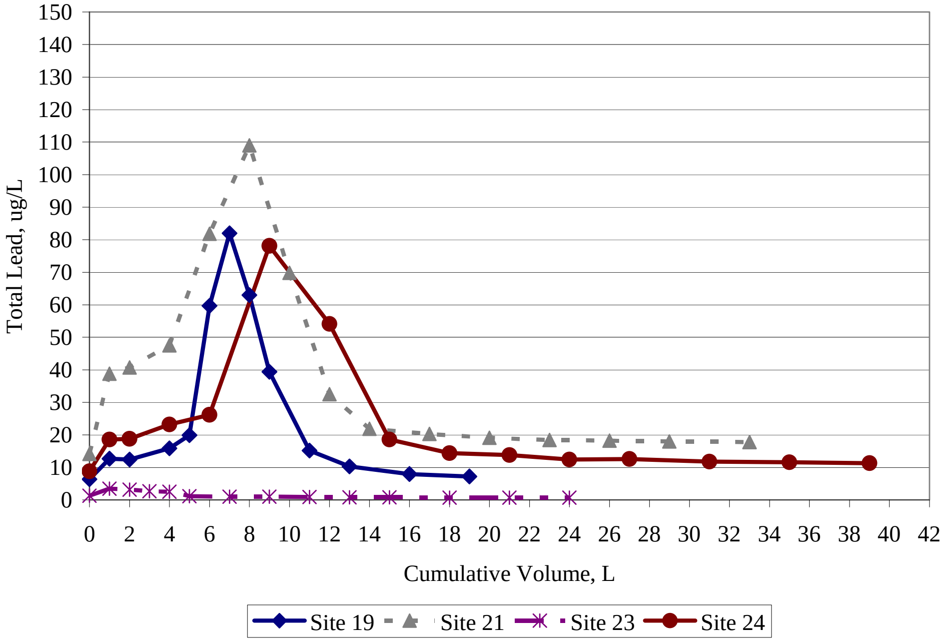


Figure H.4 Lead Profiles from Sites 19, 21, 23 and 24 (Collected in 2004 – no PO4)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

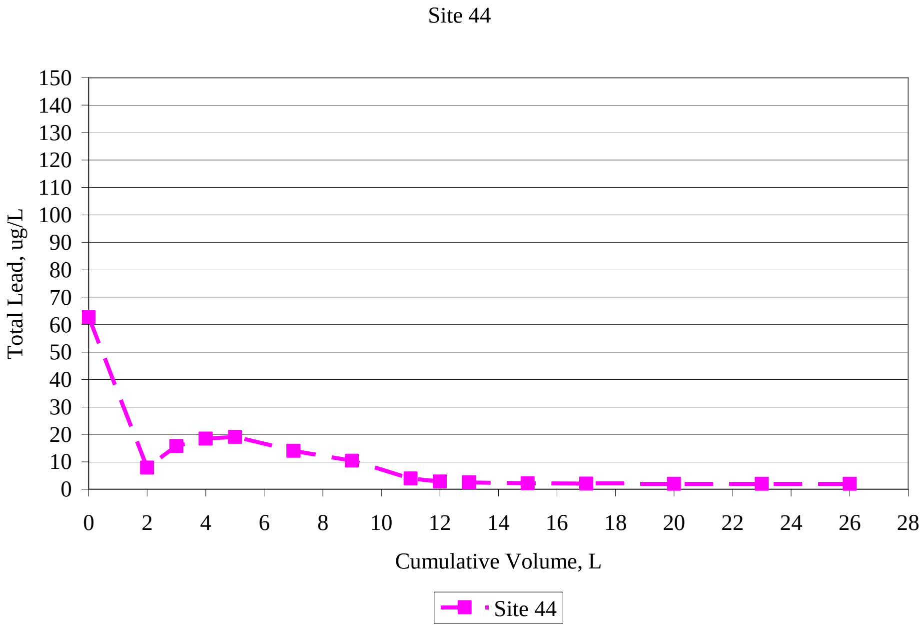


Figure H.5 Lead Profiles from Site 44 (Collected in 2004 – PO4 in use)

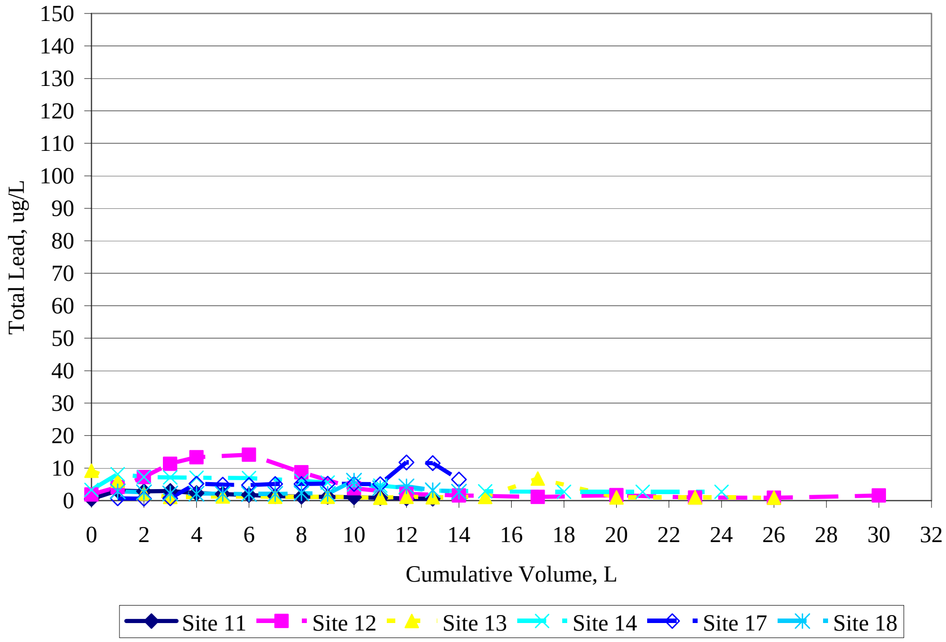


Figure H.6 Lead Profiles from Sites 11 through 14 and Sites 17 and 18 (Collected in 2005 – PO4 in Use)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

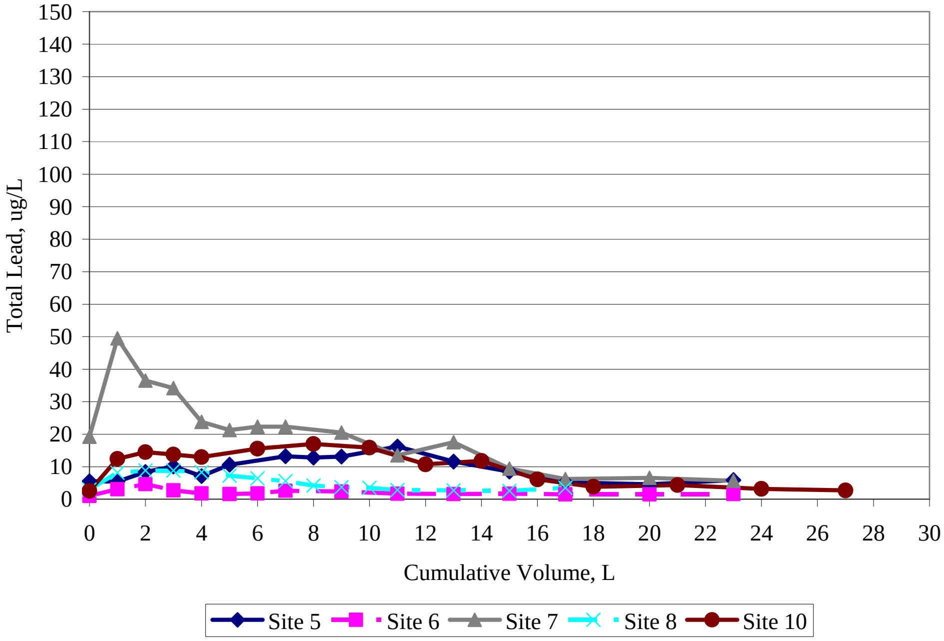


Figure H.7 Lead Profiles from Sites 5 through 8 and Site 10 (Collected in 2005 – PO4 in Use)

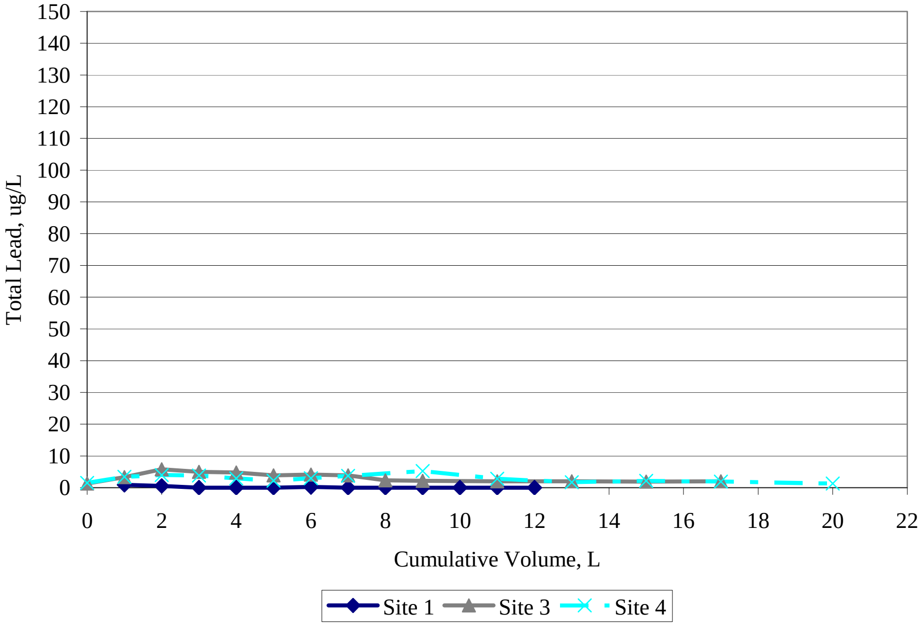


Figure H.8 Lead Profiles from Sites 1, 3 and 4 (Collected in 2006 and 2007 – PO4 in Use)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

Table H.2 lists the average lead concentrations and mass of lead calculated from samples representing the lead service from these profiles, split out between profiles collected prior to implementation orthophosphate treatment for lead control, and after implementation. Table H.3 lists the same information for samples representative of the premise piping. Reductions in average lead concentration and mass of lead were seen from both service line and premise piping samples.

Table H.2
Average Lead Concentration and Lead Mass from Lead Service Line Profile Samples – DCWASA Profiles

Year	Treatment	Average Pb Concentration, ug/L (range)	Average Pb Mass, ug (range)
Dec. 2003 – July 2004	No PO_4	58 (0.9 – 250)	250 (4 – 612)
Nov. 2004 - 2007	PO_4	8.4 (0 – 34)	46 (0 – 144)

Table H.3
Average Lead Concentration from Premise Piping (including faucet) – DCWASA Profiles

Time Period	Corrosion Treatment	Average Pb Concentration, Premise Piping, ug/L (range)	Average Premise Piping Volume, L (range)	Average Mass of Pb, ug (range)
Dec. 2003 – July 2004	No PO4	20.7 (2.3 – 50)	4 (2 – 6)	79 (12 – 167)
Nov. 2004 – April 2007	PO4	10.1 (0 – 50)	3 (2 – 6)	28 (1 – 106)

Source: *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues* by Sandvig et al.

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