

Lead Service Lines and the Lead and Copper Rule: An Overview of AwwaRF Research

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This summary of completed and ongoing AwwaRF research projects is meant to foster a basic understanding of issues specific to the relationship between lead service lines and the Lead and Copper Rule (LCR). For a more general overview of AwwaRF research related to issues surrounding distribution system corrosion and the LCR, visit the AwwaRF website at www.awwarf.org/research/TopicsAndProjects/Resources/SpecialReports/Corrosion/index.aspx and download the paper titled "Distribution System Corrosion and the Lead and Copper Rule: An Overview of AwwaRF Research"

Background

Drinking water lead and copper levels at the tap are regulated by the 1991 Lead and Copper Rule (LCR). This regulation requires utilities to meet action levels in order to control lead and copper release from distribution systems into drinking water at the tap. While the initial focus of the LCR was on water treatment strategies to reduce the corrosivity of water towards lead and copper, an important element of the LCR relates to a required action in the event that a utility cannot meet the lead Action Level (0.015 mg/L at the 90th percentile). Once a utility exceeds the Action Level, the LCR requires the utility to replace lead service lines at the rate of seven percent per year. This element of the LCR is requiring many utilities to consider full or partial removal of lead service lines.

There are many issues surrounding full or partial lead service line replacement and removal. Most utilities only own a portion of the lead service line (typically to the curb stop or meter) and therefore do not have the ability to conduct a full replacement of the service line. There are uncertainties about the contribution of utility in-line lead components, customer plumbing fixtures, and premise piping (piping within a customer's property) to lead and copper levels at the tap. Changes at the drinking water plant to reduce corrosion or reduce disinfection by-products can have both intended and unintended effects on the piping and pipe scales in service lines. Additionally, some data suggest that disturbance and cutting methods associated with partial lead service-line replacement may actually increase lead levels at the tap.

The following section summarizes the objectives, general research approach, and major findings of five AwwaRF projects that have examined various aspects of service lines as related to the LCR. Additionally, two newer ongoing projects are summarized.

The final section of this paper summarizes common themes and lessons learned from the results of this small but growing body of research.

A full listing of AwwaRF projects can be found by visiting the Project Center located on the AwwaRF website at www.awwarf.org.

AwwaRF Project Summaries

Completed Research Projects

Lead Pipe Rehabilitation and Replacement Techniques (2000, order #90789) tested and evaluated existing and emerging technologies for rehabilitation or replacement of lead pipes distribution systems. Although replacement or rehabilitation is an efficient method to remove lead sources in the distribution system, it is usually the most costly alternative for reducing lead levels at the tap (as opposed to corrosion control and source water treatment). This manual provides utilities with a tool for assessing and selecting lead pipe rehabilitation and replacement technologies. It provides descriptions of the various techniques, where those techniques can be applied, and factors that should be considered for successful application of each technique. The manual includes cost estimates (estimated in 1998) for comparison between the various techniques.

The research team used a utility survey, case studies, and field testing to document utility experience with several lead pipe rehabilitation and replacement techniques. Technology categories tested included the following:

- open-trench replacement
- replacement along existing route (discarded pipe is left in the ground and new pipe is installed along a different route using a trenchless method)
- replacement along a new route (existing lead pipe is removed or displaced while simultaneously replacing it with a new pipe)
- slip lining (existing pipe is lined with a loose or tight fitting liner made of plastic material)
- pipe coating (existing pipe interior is coated with epoxy or other polymer material)

For each technology category, the manual describes various techniques needed to apply the technology. Twenty-eight techniques were addressed in this manual. Technology profiles are detailed in the manual and facilitate a direct comparison between the various techniques.

The comparison of technologies determined the following:

- In general, the open-trench replacement technology is the most versatile and adaptable but the costs can be very high compared to other technologies (due to the typically high costs associated with site restoration).
- Replacement-along-existing-route technology is commonly applied in the United States, but not in Canada or Europe. The technology is straightforward to apply and costs are

generally lower than open trench technology – provided conditions are favorable below grade. It does tend to cause longer interruptions in water service because the water must be disconnected during replacement of the existing lead pipe.

- The replacement-on-new-route technology enables new service pipes to be installed at lower costs compared to open-trench and with minimum disruption to the environment and customers. It is commonly used in North America and Europe and is considered the most preferable technology choice for installation of replacement service pipes by many utilities surveyed for this project.
- The slip-lining technology is applied mostly in Holland and the United Kingdom. Limited testing of this technology has been conducted in North America, but it is not applied routinely. This technology can be used to rehabilitate lead pipes where replacement-along-existing-route and replacement-on-new-route technologies are not suitable. This technology would not be suitable for lead pipes that follow a convoluted route or have significant breaks or restrictions. Costs are relatively high compared to other technologies due to the cost of the lining material and high capital cost of the equipment.
- The pipe-coating technology is not used routinely in North America or Europe to rehabilitate lead pipes. It is used in the U.S. to coat small-diameter potable water pipes within buildings and ships. It can also be used to coat the inside of pipes around bends and through pipe restrictions. The major advantage of this technology is the ability to complete multiple installations at a reduced cost. The major disadvantage is the extended interruption in water service due to the long time required for the resin to cure.

Innovative Techniques for Locating Lead Service Lines (1995, order #90678) identified and evaluated various technologies and methodologies for locating buried lead service lines without the need for excavation and visual inspection. The researchers developed both direct and indirect methodologies and determined their practicality for locating lead service lines. Direct methods are technologies that permit identification of service line materials. Indirect methods use statistics to predict the presence of lead service lines by evaluating existing utility records, historical data, and construction trends.

At the time of the study, the researchers found that research and development of remote sensing equipment needed to be completed before accurate remote identification of service lines would be possible. Therefore, the study focused on devices that required contact with the pipe material. A combination of eddy-current tests, fiberscopes, and soil-vacuum excavation techniques were evaluated. Bench-scale and field tests were conducted to evaluate the performance of the locating technologies and to refine the equipment used for determining the service line materials. Mock-ups of typical meter settings and meter boxes were used to test the technologies at bench scale. For the field tests, four water utilities evaluated the performance of the equipment for various curb stop, meter, and service line configurations.

Although it was difficult, the researchers found that it possible to insert probes into service lines. Metal detectors were found to be the most promising remote sensing technology to differentiate

between metal pipe materials within 12 inches of the surface. The eddy-current probe accurately differentiated between lead, copper, and galvanized iron pipes. Difficulties existed when it was necessary to maneuver the probe past multiple 90-degree bends in the meter setting and past the curb stop valve itself. The radiodetection technology worked successfully in detecting service line locations. The vacuum-excavation technology worked successfully to expose service lines with no disruption of service. Combined use of radiodetection, vacuum excavation, and eddy-current technologies to detect lead service lines from the exterior of the pipe worked successfully in field tests.

The indirect method was developed and applied at two water utilities to test its practicality and effectiveness. The key to successful implementation of the indirect method was to develop a comprehensive database incorporating all available information related to service line installations in the system. The researchers recommend that all utilities develop databases for their tap files, incorporating information for each customer service line such as address, year of installation and replacement, and geographic location. They also recommend that the indirect method be used for initial screening of locations for lead service lines.

Development of a Pipe Loop Protocol for Lead Control (1994, order #90650) provides drinking water utilities with a standard protocol for use of the AwwaRF pipe loop to evaluate the effectiveness of various options in controlling lead and copper levels at the tap. The protocol provided is a practical, hands-on approach with construction, operation, and data evaluation recommendations based on results from several utilities that tested the AwwaRF pipe loop in their plants.

The AwwaRF pipe loop is designed to evaluate lead and copper leaching characteristics in a flow-through system that simulates household plumbing. Each loop is designed to contain several individual pipe loops for which various metal levels could be evaluated for specific water qualities. The pipe loop is designed to help utilities perform corrosion rate studies and metals leaching determinations for compliance with the LCR.

The LCR requires that all utilities serving over 50,000 customers conduct corrosion control optimization studies and demonstrate optimal treatment for lead and copper. The 1992 USEPA guidance manual for the LCR specifies a framework for conducting corrosion studies. The AwwaRF pipe loop can be used as a demonstration testing device for comparing the effect of corrosion treatments on metals levels and for testing secondary impacts of treatment changes on water quality and regulatory compliance.

Proper planning and operation are crucial for a successful pipe-loop test: this entails proper fabrication, adequate mixing of chemical feed solutions, adequate preconditioning, proper disinfection of sample ports (to prevent high heterotrophic bacteria counts), and monitoring of pipe loop operations. The operation can be divided into three phases: startup, preconditioning, and corrosion testing operations. With startup, a standard protocol for flushing is recommended in the manual. The manual also recommends a four-week preconditioning phase before chemical treatments are started. This allows verification that the pipe loops are constructed in a similar fashion and yield similar results with a common starting point for evaluating treatment effects on leaching. For the actual corrosion testing, the manual recommends a daily on-off cycle to

simulate flow in a typical home, collection of standing samples for measuring corrosion-related parameters, and collection of running samples for determining influent water quality characteristics and operational consistency. At a minimum, lead, copper, temperature, alkalinity, total and free chlorine, and pH are recommended for analysis on first-flush, standing water-quality samples. The manual recommends frequency of collection of standing samples based on the expected variability of the results and the length of time over which samples will be collected.

The manual recommends that utilities run pipe-loop tests for three distinct periods: a conditioning period, a transition period, and a stability period. The conditioning period consists of a rapid drop in metals levels, followed by a transition period where metals levels decrease at a slower rate. In the stability period, metals levels stabilize. Utilities must run the pipe-loop tests long enough to ensure data represent the stabilization period. The utilities that tested the pipe loop for this study found that it took six to nine months for lead to stabilize in lead loops, three to eight months for lead to stabilize in lead-soldered copper loops. Copper levels stabilized in two to eight months. The manual recommends utilities operate the pipe loop long enough for the metals levels to stabilize. Longer periods may be required if data collected are highly variable or a greater degree of statistical confidence is required.

In 1994, when this study was published, an AwwaRF pipe loop cost \$10,000 to \$13,000 in materials and labor to build. For several water quality conditions to be tested, one loop would be needed for each treated water condition. Operation costs may require up to one full-time operator for a two to four week period, with routine operations up to 20 hours/week.

The following drawbacks to pipe-loop testing are noted:

- For statistically meaningful and valid results, the test may have to be run for as long as 18 months to obtain adequate data.
- Metals levels measured are impacted by the nature and consistency of source water quality.
- The stability of metals may not be observed if seasonal source water quality changes happen during the course of a pipe-loop study.
- The cost of building a pipe-loop system may be cost prohibitive for small utilities.
- Variability measured in the lead and copper data from the pipe loops used in the study was high. However, nonparametric methods are available with which to evaluate the variable data in a statistically valid manner.

Although the results from the AwwaRF pipe loop must be considered a relative evaluation of treatment impacts on metal levels, the data can be used for demonstrating optimization.

Lead Control Strategies (1990, order #90559,) was published as the LCR was being first introduced in the U.S. At the time, USEPA guidance on LCR treatment plans (i.e., pipe-loop studies, analysis of data, start-up, and monitoring of treatment) had not yet been developed or published. Despite the premature timing of this study with respect to the LCR, the manual does provide a body of knowledge to help utilities develop lead control strategies.

This project identified potential sources of lead coming from customer plumbing as being goosenecks, lead service lines, lead plumbing, lead-lined iron piping, lead tin solder, and brass faucets. Many variables control the rate of leaching and lead in water samples, including the age and type of material, workmanship, size of pipe, water quality, size of the water sample, standing time, and whether a water sample has been running or standing.

As a part of this project, the research team contacted utilities that had conducted lead studies to improve water quality for their customers. The studies included water-quality tap sampling, pipe-loop studies, lead materials investigations and replacement programs, and lead treatment programs. The case studies provided a good basis for developing viable lead control strategies at the time.

The manual also provided the theory and practical considerations for controlling lead leaching from chemical treatment processes. The researchers determined the most important water quality parameters for lead solubility to be pH, alkalinity, dissolved inorganic carbonate, and orthophosphate levels. The manual recommended controlling lead with pH adjustment, carbonate adjustment, orthophosphate addition, silicate addition, and calcium carbonate deposition.

The next project summary provides water utilities with information on the performance of plastic materials that may be installed to replace lead service lines.

Water Utility Experience with Plastic Service Lines (1992, order #90593) evaluated the causes of failure of polyethylene (PE) and polybutylene (PB) service lines. The researchers evaluated the link between utility dissatisfaction with PE and PB pipe and specific pipe and fitting materials and installation practices.

In 1989 the researchers surveyed over thirty utilities, of which about half used PE pipe, ten used PB pipe, and seven used a combination of both PE and PB pipe. Overall, user satisfaction rates of 81 and 41 percent were reported for PE and PB users, respectively. PE pipe users cited failure causes from brittleness, bedding materials, and installation practices. PB pipe users cited failure causes from stress cracking, pipe kinking, and brittle failures.

PE and PB service line samples were tested in the laboratory for causes of failure. For PE pipe, no single failure mode dominated. However, failure due to installation-related factors did predominate (e.g., bedding materials, pipe kinking from insufficient slack or bending, and splitting and cracking from settlement stresses). For PB pipe, kinking was the predominant failure cause. A majority of the samples demonstrated short oxidation induction times although significant oxidation could occur before the pipe integrity was negatively affected. In all samples, oxidation was consistent throughout the pipe walls. The researchers postulated that antioxidant was not present in the original resin in sufficient amounts or that antioxidant compounds were lost during the pipe extrusion process.

Ongoing Research Projects

Contribution of Service Line and Plumbing Fixtures to LCR Issues (project #3018) is researching and quantifying the contribution of lead service lines, utility-owned plumbing fixtures, and customer-owned plumbing fixtures to LCR compliance issues. The research team is planning a three-phased approach to the research.

During the initiation phase, the researchers plan on conducting a literature review, preparing a series of issue papers, and then holding an expert workshop to develop the framework for issues surrounding lead service lines and customer plumbing and the LCR.

The second phase of the project will consist of a utility survey and various levels of field testing. The survey will gather information on issues related to utility-owned and customer-owned lead sources in distribution system and premise piping. Case studies will focus on utility experiences with partial and full lead service line replacement, leaded meter replacement, and low-lead fixture replacement programs. Field testing will identify sources of lead in service and premise plumbing and develop best management practices for partial replacement of lead service lines. Laboratory and pilot testing will evaluate lead contributions from lead-containing materials (service lines, meters, and faucets) and will assess the composition of scale layers formed on the interior of lead bearing distribution and premise plumbing components.

The final report will document and summarize the case studies, historical water quality data from utilities, laboratory and pilot plant test results, and water quality and scale composition data. Additionally, the research team will develop criteria and guidance to assist utilities in making decisions about the effectiveness of lead source replacement versus corrosion treatment.

This project begins in January 2005 and will end in the fall of 2008. The research team is led by Gregg Kirmeyer and Anne Sandvig of Economic and Engineering Services, Inc./HDR Engineering.

Installation, Condition Assessment, and Reliability of Service Lines, Connections, and Fittings (project #2927) is identifying parameters and conditions that influence the failure rate of service pipe materials, connections, and fittings. The research team has divided the project into three major phases: problem identification, investigation and data analysis, and development of a best practices manual.

During the problem identification phase, the research team conducted a literature review and utility survey, as well as documented case studies on utility experiences with selection of materials, installation, condition assessment, and rehabilitation of service lines, connections, and fittings. An expert workshop was held as an information exchange between utilities and industry experts on methods for service-line life predictions, differing building and plumbing codes, and identification of service-line related problems that should be addressed by this and future research efforts.

During the investigation and data analysis phase, the research team will conduct field research to determine causes of service-line failures. Additionally, the research team will conduct lab-scale tests on soil and pipe interactions and will review leak detection technologies. The research team also plans on collecting information on insurance policies for service line repairs/rehabilitation projects.

The final product of this project will be a best practices manual to identify parameters and conditions that influence the failure rate of service pipes, connections, and fittings. Included in the manual will be a decision tree for selection of the best material and installation techniques for a given application or set of environmental conditions.

This project began in January 2004 and will end in the spring of 2006. The research team is led by Dave Cornwell and Yann LeGouellec of Environmental Engineering and Technology, Inc.

Summary of results/common themes

AwwaRF research conducted on lead service lines thus far provides tools that help utilities manage their existing service line inventory and evaluate replacement options for lead service lines.

- *Lead Pipe Rehabilitation and Replacement Techniques* (2000, order #90789) is a practical tool for assessing and selecting lead pipe rehabilitation and replacement techniques. The report profiles and provides a direct comparison of five technology categories (open-trench, replacement along existing route, replacement along a new route, slip lining, and pipe coating) for lead service line replacement.
- Before considering a full or partial lead service line replacement program, a system-wide inventory needs to be undertaken to determine the location of lead service lines. *Innovative Techniques for Locating Lead Service Lines* (AwwaRF 90678, 1995) outlines both direct and indirect methods for locating lead service lines. The researchers recommend that all utilities develop databases for their service line tap files, incorporating information for each customer service line such as address, year of installation and replacement, and geographic location. They also recommend that the indirect method be used for initial screening of locations for lead service lines.
- The AwwaRF pipe loop protocol (*Development of a Pipe Loop Protocol for Lead Control*, AwwaRF 90650, 1994) offers a practical, hands-on approach to evaluate lead and copper leaching characteristics in a flow-through system that simulates household plumbing. It is a useful tool for determining metals leaching for service line and plumbing components, but is expensive and time-consuming to use.
- When considering the various pipe material options for service line replacement, utilities should review *Water Utility Experience with Plastic Service Lines* (AwwaRF 90593, 1992) to read about water utility experience with failure of polyethylene (PE) and polybutylene (PB) service lines. At the time of the study, utility satisfaction rates of 81 and 41 percent were reported for PE and PB users, respectively.

Future Work

Two projects related to lead service lines were approved by the AwwaRF Board of Trustees for funding as a part of the 2005 AwwaRF research agenda. Requests for proposals (RFPs) are scheduled to be released in March 2005.

- "Performance and Metals Release of Non-Leaded Brass Meters and Fixtures" (RFP #3112). This project would define issues, determine the current state of knowledge, and identify research gaps and needs with the increased and widespread use of non-lead brass (or "enviro" brass) meters and fixtures by the drinking water industry. This project would build the framework for researching how these new non-lead fixtures perform in the short and long term as well as what water quality impacts they may have on finished drinking water at the tap after installation. It would also help to develop a research plan to investigate specification and operations and maintenance issues associated with the use of these new non-lead brass fixtures.
- "Impact of the Change in Disinfectants on Lead, Brass, and Copper Components in the Distribution System" (RFP #3107). This project would determine the effect of changing disinfectants (from free chlorine to chloramines and vice versa) on metals leaching rates and leaching levels from lead, brass, and copper distribution system components. This project would also study the effects of galvanic coupling on metals release.

Additionally, AwwaRF continually strives to help utilities prepare for the future through new drinking water research.

Starting in early 2005, the four workgroups of the AwwaRF Research Advisory Council (RAC) will be considering new research ideas and will develop a solicited research agenda for 2006. The RAC workgroup members are volunteer drinking water industry professionals – utility representatives, consultants, regulators, AWWA committee members, and academicians. They evaluate and consider research ideas collected from the drinking water community in order to develop next year's solicited research agenda. The four workgroups that make up the body of the RAC – High Quality Water, Infrastructure Reliability, Environmental Leadership, and Efficient and Customer Responsive Organization – will carefully consider any lead service line related issues and if they see a research need of high priority, will develop projects to release for RFP in 2006.

To submit specific research ideas related to the topic of lead service lines and the LCR, please contact Traci Case, AwwaRF Project Manager, at 303.347.6120 or tcase@awwarf.com as soon as possible, but no later than August 1, 2005.

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Report Title	Year Published	Order #	Principal Investigator
<i>Lead Pipe Rehabilitation and Replacement Techniques</i>	2000	90789	Kirmeyer (Economic and Engineering Services, Inc.)
<i>Innovative Techniques for Locating Lead Service Lines</i>	1995	90678	Deb (Roy F. Weston, Inc.)
<i>Development of a Pipe Loop Protocol for Lead Control</i>	1994	90650	Kirmeyer (Economic and Engineering Services, Inc.)
<i>Lead Control Strategies</i>	1990	90559	Economic and Engineering Services, Inc.
<i>Water Utility Experience with Plastic Service Lines</i>	1992	90593	Thompson (Brown and Caldwell Consultants)