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Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events, Final Summary Report

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Final Summary Report

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EXECUTIVE SUMMARY

The District of Columbia Water and Sewer Authority (DCWASA) owns and operates a system that delivers water produced by the U.S. Army Corps of Engineers Washington Aqueduct (WA) to customers in Washington, D.C. During compliance monitoring for the Lead and Copper Rule (LCR) in July 2000 through June 2001, DCWASA exceeded the 15-μg/L action level (AL) for lead at the 90th percentile in home tap sampling. DCWASA repeatedly exceeded the AL during subsequent monitoring through the period ending in December 2004.

A combination of factors – not a single source or a single causative event – contributed to the problematic release of lead in water at consumers' taps in the DCWASA system. The primary source of lead release was attributed to the presence of lead service lines (LSLs) in the DCWASA service area. Since the mid-1990s, three notable occurrences in the DCWASA system likely contributed to elevated lead releases during 2000 through 2004. These are highlighted below.

- During the mid-1990s, the concentration of residual free chlorine was increased to the range of 2.2 to 3.2 mg/L for the purpose of controlling coliform occurrence in the water distribution system. These relatively high free chlorine concentrations likely facilitated the formation of Pb (IV) scales in the form of lead dioxide (PbO_2) in lead service pipes. These Pb (IV) scales exhibit relatively low lead solubility under normal ranges of pH and alkalinity in public water systems when compared to Pb (II) compounds. Lead scales on the interior of lead service lines are likely comprised of various forms of lead, including both Pb (II) and Pb (IV), and the chemical composition of the scales likely changes with varying water quality conditions.
- The pH of the distributed water in Washington, D.C. exhibited seasonal variations that fluctuated from approximately 7.0 to 8.9 during the period from 1992 to 2004. pH levels at the lower end of this range would not be considered optimal for lead corrosion control according to the conventional understanding that forms the basis for the LCR and assumes the presence of Pb (II) as the dominant scale. In D.C., however, and as stated above, relatively high free chlorine concentrations likely facilitated the formation of Pb (IV) as the dominant scale, which exhibits relatively low lead solubility at the lower pH levels experienced in the DCWASA system.
- On November 1, 2000, WA converted the residual disinfectant from free chlorine to chloramines for the purpose of lowering disinfection byproducts to meet new regulatory requirements. This conversion facilitated a reduction in oxidation reduction potential (ORP) to a range that favors the predominance of Pb (II) scales, which are highly influenced by low and fluctuating pH levels. This conversion from free chlorine to chloramines likely changed the nature of the predominant scale from Pb (IV) to Pb (II) and thus facilitated an increase in the release of lead from the lead service lines into the water at consumers' taps.

1. INTRODUCTION AND SUMMARY

This section provides the following:

- Background information regarding operating conditions and events prior to and during the monitoring periods when the District of Columbia Water and Sewer Authority (DCWASA) exceeded the lead action level (AL) of the Lead and Copper Rule (LCR) during compliance monitoring in 2000 through 2004.
- A description of the study's purpose and an in-depth analysis of potential causative events.
- A summary of the findings of the study. Possible causes of high lead levels in DCWASA tap samples are identified and discussed.
- An overview and road map for the reader regarding the contents of subsequent sections in this report.

1.1 Background

DCWASA owns and operates a system that delivers water to Washington, D.C. Water is diverted from the Potomac River and treated at two water treatment plants, Dalecarlia and McMillan, operated by the U.S. Army Corps of Engineers' Washington Aqueduct (WA). Both water treatment plants provide finished drinking water to the DCWASA service area.

Historically, full conventional treatment has been provided using aluminum sulfate (alum) for coagulation, gravity filtration, free chlorine for disinfection, fluoride addition for dental health, and lime addition for reducing corrosion (USACE, 2006). The pH of the distributed water exhibited seasonal variations that fluctuated from approximately 7.0 to 8.9 from 1992 to 2004. During the mid-1990s, WA increased the concentration of free chlorine to the range of 2.2 to 3.2 milligrams per liter (mg/L) for the purpose of controlling coliform occurrence in the DCWASA distribution system. On November 1, 2000, WA converted from using free chlorine to chloramines at both plants to provide a residual disinfectant in the distribution system less likely to form regulated disinfection byproducts. In August 2004, orthophosphate was added at both plants for corrosion control and pH levels were adjusted to accommodate this new chemical treatment.

DCWASA met the lead AL of 15 micrograms per liter (μg/L) per the LCR during compliance monitoring from July 1994 through September 1999. In February 2000, USEPA Region 3 reduced the requirement for LCR tap monitoring to once per year at 50 sites as allowed by the LCR. At the request of WA and DCWASA, the minimum pH requirement at entry points and distribution system sites was lowered and the letter of OCCT designation was implemented with the approval of United States Environmental Protection Agency (USEPA) effective July 1, 2000.

Subsequently, average pH levels were observed to be as low as approximately 7.0 in the distribution system during 2001 and 2002. Reduced monitoring continued through the LCR compliance monitoring period of July 2001 – June 2002 because DCWASA had reported LCR 90th percentile monitoring results below the regulatory AL during July 2000 – June 2001. In 2004, USEPA Region 3 reassessed 90th percentile results for the LCR monitoring period of July 2000 – June 2001. USEPA determined that the originally reported LCR 90th percentile values had not included all samples, and that the AL had been exceeded during the July 2000 – June 2001 LCR compliance monitoring period (Rizzo, 2005b). DCWASA also exceeded the AL in five LCR monitoring periods subsequent to the July 2000 – June 2001 monitoring period. DCWASA was required by USEPA to implement, among other LCR requirements that follow exceedance of the AL, a lead service line replacement program per the LCR. A lead service line replacement program was commenced in June 2003.

1.2 Purpose of Study

The presence of lead is pervasive in piping systems and plumbing components including lead service lines (LSLs), brass faucets, lead-tin solder, meters, valves, and other components. Lead can enter the water supply from lead-bearing materials in either the soluble or particulate form.

USEPA decided to perform an in-depth analysis that would document and determine, to the extent possible, the source(s) and cause(s) of elevated lead levels at DCWASA consumers' taps. USEPA anticipates that this evaluation, which is summarized in this document, can be used by USEPA, states, and public water systems to assist in their efforts to reduce lead in drinking water and avoid the conditions that resulted in elevated lead levels in Washington, D.C. in 2000 – 2004.

1.3 Study Findings

This section provides the following:

- A summary of findings, including an evaluation of the combination of factors that contributed to lead release at consumers' taps.

- A description of the causative events and possible sources of lead that contributed to lead releases in the DCWASA service area.

1.3.1 Combination of Factors that Contributed to Lead Release

Figure 1 illustrates the timeline of events from 1992 to 2004 highlighting operations and regulatory compliance decisions, 90th percentile lead levels, shifts in disinfectants and pH, coliform events, and other key dates and related activities associated with lead released at consumers' taps in the DCWASA service area.

Based on a review of existing conditions and service line profiling, the primary source of lead release was attributed to the presence of lead service lines in the DCWASA service area. Since the mid-1990s, three notable occurrences in the DCWASA system likely contributed to elevated lead releases during 2000 through 2004. These notable occurrences pertained to water quality changes and conditions as described below.

- The first notable water quality change occurred in the mid-1990s when the concentration of residual free chlorine was increased to 4.0 mg/L and subsequently maintained in the range of 2.2 to 3.2 mg/L; this change was implemented for the purpose of controlling coliform occurrence in the water distribution system.

  These relatively high free chlorine concentrations likely facilitated the formation of Pb (IV) scales in the form of lead dioxide (PbO_2) in lead service lines. The conventional understanding that forms the basis for the LCR assumes the presence of Pb (II) as the dominant scales. Lead scales on the interior of lead service lines are likely comprised of various forms of lead, including both Pb (II) and Pb (IV), and the chemical composition of the scales likely changes with varying water quality conditions. Lead dioxide scales generally exhibit relatively low lead solubility under normal ranges of pH and alkalinity in public water systems when compared with Pb (II) compounds.

- The second notable water quality condition pertains to the fluctuating and low pH of the water in the DCWASA system. pH of the water is an important factor in the control of lead solubility. The pH of the distributed water in Washington, D.C. exhibited seasonal variations that fluctuated from approximately 7.0 to 8.9 during 1992 to 2004. pH levels at the lower end of this range are not considered optimal for lead corrosion control based on the conventional understanding of lead solubility per the LCR, assuming that Pb (II) is the dominant form of scales.

  In Washington D.C., as stated above, relatively high free chlorine concentrations applied to the service area during the mid-1990s likely facilitated the formation of Pb (IV) as the dominant scale. Pb (IV) exhibits relatively low lead solubility at the lower pH levels experienced in the DCWASA system. Consequently, lead levels were low during LCR compliance monitoring during the mid-1990s.

- The third notable water quality change occurred when WA converted the residual disinfectant from free chlorine to chloramines beginning November 1, 2000. The residual disinfectant conversion was implemented for the purpose of lowering disinfection byproducts to meet new regulatory requirements. This conversion facilitated a reduction in oxidation reduction potential (ORP) to a range that favors the predominance of Pb (II) scales. Pb (II) species generally are highly influenced by low and fluctuating pH levels. This conversion from free chlorine to chloramines likely facilitated the release of lead in water while operating at low, fluctuating pH conditions. Lead release likely increased after pH was allowed to drop further when the minimum pH requirements at entry points and distribution sites were lowered at the request of WA and DCWASA and implemented with the approval of USEPA effective July 1, 2000.

In summary, the combination of the three water quality conditions described above – historical use of elevated free chlorine concentrations, low pH operating levels and pH variations, and conversion from free chlorine to chloramines – in addition to the presence of lead service lines in the DCWASA service area, likely caused and contributed to elevated lead levels during LCR compliance monitoring periods from July 2000 through December 2004.[*]

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[*] It should be noted that not all systems containing lead-bearing materials are expected to exceed the LCR 90th percentile for lead when implementing a switch from free chlorine to chloramines.

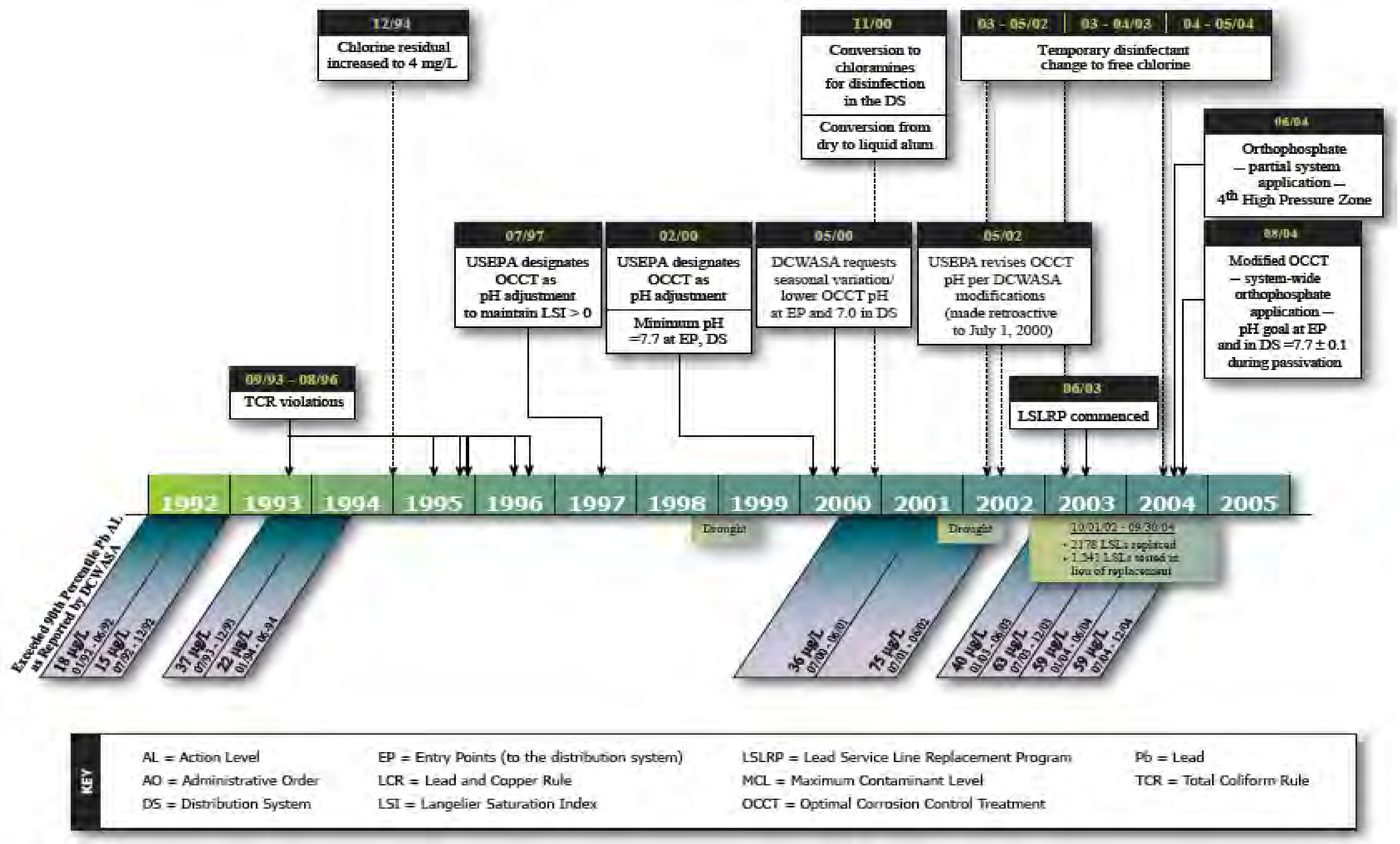


Figure 1. Timeline of operational events and key regulatory determinations for the DCWASA system

[Note: DCWASA either met the Action Level or was not required to perform monitoring from 1994 to 2000. Available LCR compliance data for DCWASA are summarized and discussed in Section 2 of this report.]

1.3.2 Causative Events

This section identifies possible causative events and provides an evaluation of the relative contribution of each event to elevated lead levels in DCWASA consumers' taps. For the purpose of this report, a causative event is defined as a notable occurrence, such as change in treatment or operations, or an external event or condition that potentially affected water quality and lead release in the DCWASA system.

The primary source of lead release was attributed to the presence of lead service lines in the DCWASA service area (see Section 1.3.3). Findings pertaining to causative events are summarized in Table 1 and discussed below.

Table 1. Summary of possible causative events affecting lead release

Causative Event	Evidence and Likelihood of Causative Event Affecting Lead Release in Water at Consumers' Taps
Historical use of elevated free chlorine concentrations	The increase in free chlorine concentration in the mid-1990s likely modified ORP conditions in the DCWASA service area that would facilitate a change in predominant lead scales from Pb (II) to Pb (IV) species. Theoretical considerations support the likelihood that lead solubility would be lower for Pb (IV) species in DCWASA water. Although the system was operated at low and varying pH levels, DCWASA met the AL during LCR compliance monitoring from 1994 to 2000.
Distribution system pH levels and pH variations	pH levels and pH variations appear to be important contributing factors to high lead release from scales. Low and varying pH levels in the system were not optimum for lead control, especially Pb (II) control.
Conversion from elevated free chlorine to chloramines for final disinfection	The change in disinfectant from elevated free chlorine levels to chloramines likely modified redox conditions that would facilitate a change in predominant lead scale from Pb (IV) to Pb (II) species. Based on available evidence, it is highly likely that the different oxidation-reduction potential of the water and responses of scales were involved in significant lead release, especially at low pH levels.
Drought conditions	Statistical analyses of specific conductance, alkalinity, and temperature were performed during drought conditions. Data yield no definitive trends.

1.3.2.1 Historical Use of Elevated Free Chlorine Concentrations

Lead scales on the interior of lead service lines are likely comprised of various forms of lead, and the chemical composition likely changes with changing operating conditions including changes in water quality. As mentioned previously, the concentration of residual free chlorine was increased during the mid-1990s to the range of 2.2 to 3.2 mg/L for the purpose of controlling coliform occurrence in the water distribution system.

These relatively high free chlorine concentrations likely facilitated the formation of Pb (IV) scales in the form of PbO_2 in lead service lines.

Analysis of lead service line specimens by Schock and Giani (2004) confirmed that tetravalent lead (Pb (IV)) scale was present on interior lead pipe surfaces in the DCWASA system. The Pb (IV) solid, PbO_2, is thought to be much less soluble over the normal range of pH and alkalinity in public water systems than common Pb (II) solids including cerussite, $PbCO_3$, and hydrocerussite, $Pb_3(OH)_2(CO_3)_3$, as described by Schock et al. (2001). Accordingly, the relatively high redox potential of the DCWASA water due to the high free chlorine concentration likely reduced the amount of lead release from lead pipe, and therefore, DCWASA met the AL during LCR compliance monitoring from 1994 to 2000.

1.3.2.2 Distribution System pH Levels and pH Variations

Conventional understanding of lead control in drinking water per the LCR is based on the presumption that Pb (II) solids control lead solubility and that manipulation of basic water chemistry (pH, alkalinity) can produce stable mineral forms, including cerussite and hydrocerussite, that passivate a corroding lead surface. Typically, lower pH levels contribute to higher lead solubility, and higher pH levels are associated with lower lead solubility.

The Potomac River source water quality fluctuates seasonally and some of these fluctuations are observed in the finished water. To avoid significant calcium carbonate ($CaCO_3$) precipitation, minimum pH levels in the finished water were varied seasonally as established by the USEPA on May 17, 2002 (retroactive to the monitoring period beginning July 1, 2000) as Optimal Corrosion Control Treatment (OCCT). As such, the pH of water entering the distribution system was purposefully varied by WA. The pH varied even more within the distribution system due to other factors such as seasonal fluctuations and site-specific conditions in the distribution system.

Historical water quality data collected at the Dalecarlia and McMillan water treatment plants indicate seasonal pH fluctuations that varied from approximately 7.5 to 8.8 during 1992 to 2004. Distributed water pH was allowed to drop further below pH 7.5 when the pH requirements at entry points and distribution sites were lowered at the request of WA and DCWASA and implemented with the approval of USEPA effective July 1, 2000. The lowering of average pH values during monitoring periods from July 2000 to December 2004 is an important factor that potentially contributed to lead release in DCWASA tap water, especially when chloramination conditions favored the formation and dominance of Pb (II) scales.

Elevated lead levels were reported during the July 2000 – June 2001 LCR monitoring period. pH fluctuations occurred before, during, and after the July 2000 – June 2001 LCR monitoring period. Thus, pH fluctuations alone were not likely the cause of elevated lead levels. Before the disinfectant conversion to chloramines, DCWASA met the requirements of the LCR while using elevated free chlorine concentrations. DCWASA exceeded the AL for lead during the monitoring period that coincided with the change in disinfectant and the lowering of the operating pH level. The change in pH operating levels, and pH variations in the distribution system, were therefore likely contributing factors to elevated lead levels at consumers’ taps.

1.3.2.3 Conversion from Elevated Free Chlorine to Chloramines for Final Disinfection

On November 1, 2000, DCWASA converted from free chlorine to chloramines as the residual disinfectant to reduce the potential formation of regulated disinfection byproducts. As stated earlier, the relatively high concentration of free chlorine that was used for residual disinfection prior to the conversion to chloramines likely facilitated the formation and predominance of Pb (IV) species in lead service lines and other lead-bearing components. The different oxidation potentials of elevated free chlorine and chloramines, and the responses of lead scales (found on lead service lines, and possibly other lead-bearing components) to this change in disinfectant were likely significant factors in the release of lead into tap water.

Theoretical and empirical evidence documenting this potential cause of lead release includes the following: lead scale analysis, scale formation and solubility analysis, and tap sampling from lead service lines. Common Pb (IV) solids in an elevated redox condition, such as in the presence of elevated free chlorine, include PbO_2. In comparison, common Pb (II) solids at lower redox conditions are generally considered to be predominated by lead species such as cerussite and hydrocerussite (Schock et al., 2001). Hence, changing the oxidation-reduction state of the water through a disinfectant change likely increased the amount of lead release from lead pipe. The change from elevated levels of free chlorine to chloramines lowered the ORP of the distributed water, likely causing a shift in predominance from Pb (IV) to Pb (II) species, and thus facilitating the release of lead at consumers' taps.

Further, tap sampling in the form of lead profiling conducted at specific home locations before and after the temporary disinfectant change in 2004 provides additional information regarding the likelihood that this conversion was a factor in lead release by the service line and uptake by water passing through the pipe.

1.3.2.4 Drought Conditions and Effects on Corrosivity of DCWASA Water

Drought conditions may have resulted in different water quality conditions in the source waters that could have influenced finished water quality and corrosion potential. There is a substantial amount of information and data on the source water quality during these time periods, but it is difficult to relate it to the corrosion potential of the distributed water. The statistical analysis of specific conductance, alkalinity, and temperature during drought conditions, which was conducted as part of this investigation, does not implicate drought as a major factor in lead release. Drought conditions may have played a contributing role in increased lead corrosion; however, the impact of drought conditions on water quality parameters that affect corrosion was not investigated further.

1.3.3 Potential Sources of Lead Release

This section identifies possible sources of lead in the DCWASA system. For the purpose of this report, a source of lead release is defined as a piping material or plumbing component that contains lead, including brass faucets, lead service lines, solder, meters, etc. Galvanic corrosion and electrical grounding are also included in this discussion because these conditions can induce the release of lead from a piping material or plumbing component. This section also provides an evaluation of the relative likelihood of lead release from each of the possible sources. Findings are summarized in Table 2 and discussed below.

Table 2. Summary of possible sources of lead release

Source of Lead	**Evidence and Likelihood of Source Affecting Lead Release in Water at Consumers' Taps**
Lead service lines	Lead profiling indicates that the majority of lead released is from lead service lines and is predominantly in the soluble form. Intermittent spikes of particulate lead were noted.
Faucets, solder, and other home plumbing	Lead profiling indicates some contribution, but these sources are likely not the major contributor. Findings related to this causative factor are also based on reported lead release from premise piping components in similar plumbing systems.
Galvanic corrosion of lead service lines	Data are limited but indicate low likelihood of contribution to lead release.
Grounding currents	Data are limited but indicate low likelihood of contribution to lead release.
City-wide meter replacement	Data are limited and indicate some soluble lead release. Major impact on lead levels at consumers' taps is unlikely.
Distribution mains	Published reports indicate that this source is not a meaningful source of lead. Some flushed samples are very low in lead levels and others are elevated, which is likely due to release of lead from service lines and premise piping rather than from distribution mains.

1.3.3.1 Lead Service Lines

Given that many service lines connected to the DCWASA distribution system are made of lead, and profiling indicates that the majority of lead release was from lead service lines, lead service lines are therefore considered the major source of lead release in the DCWASA system. Further, lead scales on the interior of lead service lines likely are comprised of a variety of compounds that co-exist in the lead scales. The conversion to chloramines, along with varying pH levels, likely affected the stability of scales and thus resulted in release of lead from the lead service lines and uptake by water at consumers' taps in the DCWASA system.

The potential exists for lead-bearing scales to be detached from the service line or home plumbing during plumbing disturbances and to enter the water column as particles. One example of this scenario is the disturbance associated with partial replacement of lead service lines, which results in release of lead scales from the portion of the line remaining in service. Particulate lead spikes do occur in tap samples, but they are relatively infrequent, of short duration, and thus are not likely the major factor in causing the sustained high lead levels at the consumers' taps.

1.3.3.2 Faucets, Solder, and Other Home Plumbing

Faucets, solder, and other home plumbing can potentially contribute to total lead measured in water collected at the tap. Brass faucets and 50 : 50 tin : lead solder, historically used to join copper piping in home plumbing systems, contain lead. Lead profiling indicates that home plumbing components are a likely contributing source, but not the major source of lead in tap samples. Analogous lead profiling data also indicate that common end-use plumbing components contribute lead to standing water. In addition to site-specific lead profiling, industry data demonstrate that home plumbing potentially contributes to total lead. However, available data do not provide compelling evidence that faucets, solder, and other home plumbing were predominant lead contributors in the DCWASA service area.

1.3.3.3 Galvanic Corrosion of Lead Service Lines

In the service lines and premise piping systems, there are sites where lead and other metals are directly connected, resulting in galvanic couplings. The coupling of these dissimilar metals could result in the release of lead to the water. There is very little information on this potential cause and no site-specific data are available for review. A laboratory investigation of this issue conducted by Reiber and Dufresne (2005) regarding DCWASA conditions indicates that galvanic couplings likely contribute very little to lead release.

1.3.3.4 Grounding Currents that Affect Corrosion of Lead-Bearing Components

It is possible that lead may be released to the water column at sites where the electrical systems have been grounded to water piping systems. There is very little information on the potential effect of grounding currents on corrosion of lead-bearing materials, and no site-specific data are available. An investigation of this cause conducted by Reiber and Dufresne (2005) regarding DCWASA conditions indicates that grounding likely contributes very little to lead release.

1.3.3.5 City-Wide Meter Replacement Program

There are two potential sources of lead release and uptake by the water associated with meter replacement: (1) disturbance of adjacent piping, causing release of scales containing lead (particles); and (2) release of soluble lead directly from the meter itself due to water chemistry. There are data available on water quality conditions and the effect on lead release from meters in a site-specific study (Keefer and Giani, 2005). However, little or no data are available on the potential release of particulate lead associated with meter replacement. Testing of meters for lead release indicated that some release occurred, but the contribution is small and likely not a major contributor to elevated lead at the tap.

1.3.3.6 Distribution Mains

Water in the utility's distribution mains was assessed during this study by reviewing pertinent reports and by evaluating lead profiling data collected after a thorough flushing of the tap for a period considered sufficient to bring fresh water in from the main. The reports (Keefer and Giani, 2005; Giani et al., 2005a) indicate that lead from the distribution system is very low. However, lead profiling yielded conflicting data regarding the presence and contribution of lead in the distribution mains. Many flushed samples were reported at detection limits for lead, but others were reported at elevated lead levels. The higher than expected lead levels could have been caused by either release of lead from components in the utility system, or by release of lead from the lead service lines or premise piping and plumbing. Based on available data and information, it is the study team's best professional judgment that the distribution system components were not a major contributing factor in lead levels at consumers' taps.

1.4 Organization of Report

This section (Section 1) summarizes the findings of a study conducted by HDR/EES to document and evaluate the potential causative events and parameters contributing to the elevated lead levels in the Washington, D.C. drinking water system. The remaining sections of this report provide supporting data, information, and discussion. The contents of the remaining sections of this report are highlighted below.

- **Section 2** describes the history of DCWASA's lead monitoring program and HDR/EES's independent evaluation of reported compliance data.

- **Section 3** provides documentation of reported water quality data at distribution system entry points (i.e., the Dalecarlia and McMillan Water Treatment Plants) and findings from sanitary surveys of water treatment facilities.

- **Section 4** provides documentation of water quality data collected in the distribution system, identification of the occurrence and evaluation of lead sources, and findings from sanitary surveys in the distribution system.

- **Section 5** provides an evaluation of the combination of factors that contributed to the problematic release of lead. This section also provides an in-depth discussion of causative factors that potentially contributed to elevated lead levels including each of the possible causative events (i.e., historical use of elevated free chlorine concentrations; distribution system pH levels and pH variations; conversion from free chlorine to chloramines for final disinfection; and drought conditions) and each of the identified possible sources of lead release (i.e., lead service lines; faucets, solder, and other home plumbing; galvanic corrosion of lead service lines; grounding currents; city-wide meter replacement; and distribution mains).

- **Section 6** provides a brief summary of the current LCR compliance status of the DCWASA system and it identifies possible follow-on work based on available findings and conclusions drawn from this study.

Documents prepared as part of this evaluation include: (1) this Summary Report, (2) supporting hard copy materials in three-ring binders, and (3) a data evaluation report per the requirements of the Quality Assurance Project Plan (QAPP).

2. HISTORY AND EVALUATION OF LEAD MONITORING PROGRAM

This section includes the following:

- The sampling protocols used for first- and second-draw sampling.
- DCWASA's 90th percentile calculations for first- and second-draw lead results and HDR/EES's reassessment of those results.
- USEPA Region 3 designation of OCCT.
- Description of DCWASA's lead service line replacement program.

USEPA Region 3 provided HDR/EES with laboratory sample reports; 90th percentile calculations; and correspondence related to LCR monitoring, including first-draw and second-draw samples. To facilitate data evaluation, hard copies of LCR compliance data were entered into Excel® spreadsheets. In addition, HDR/EES received electronic data files containing compliance monitoring data for the compliance periods of January through June and July through December of 2004.

2.1 Sampling Protocols

First- and second-draw samples were analyzed for lead, copper, and iron using EPA Method 200.8 at WA's certified laboratory. In addition, USEPA Region 3 provided correspondence on designation of OCCT.

It appears that first-draw samples were collected by homeowners per LCR protocol. Although not required by regulations, homeowners have routinely collected a second-draw sample from their taps as well as requested by DCWASA. The protocol for collecting this second-draw sample has changed through the years as described below. DCWASA's 2004 sampling instructions directed homeowners to collect first-draw samples after a 6- to 8-hour period of no water use. The second-draw sample was collected at the same tap after allowing the water run at a slow pace until the water turned cold. Prior to 2004, second-draw samples were collected immediately after the first-draw sample without allowing the water to run until there was a temperature change (Rizzo, 2005b). G. Rizzo of USEPA Region 3 estimated that DCWASA had been using this sampling procedure for second-draw samples for several years prior to the LSL replacement program, which commenced in 2003 (Rizzo, 2005b).

Prior to June 2002, information was not readily available regarding the recommended protocol, nor were specific instructions on whether to remove the faucet aerator device when collecting tap samples for LCR monitoring. In June 2002, which corresponds to the last month of the July 1, 2001 through June 30, 2002 monitoring period, customers were instructed to remove aerators. Following this, for the January 1 to June 30, 2003 full monitoring period, customers were again instructed to remove the devices before sampling. This changed from the July 1 to December 31, 2003 monitoring period onward, when customers were instructed to leave the aerators in place. Currently, these instructions requiring customers to leave the aerators in place are still provided as the appropriate sampling protocol (Smith, 2006). Similarly, instructions or a protocol for removal of point-of-use (POU) treatment devices during LCR sampling were not defined until 2004 (Rizzo, 2004).

The relevance of both the aerator removal protocol and POU devices to lead levels and LCR monitoring are discussed in Section 5 of this report.

2.2 First-Draw Lead Results

This section provides documentation of historical LCR first-draw lead sampling results as reported by DCWASA and an evaluation of these data by HDR/EES. This section also provides a summary of the 90th percentile reassessment by USEPA.

2.2.1 Historical Data

For LCR first-draw lead results, 90th percentile calculations prepared by DCWASA were reviewed and re-calculated using either tabular data, laboratory data sheets, or Excel spreadsheet data received from USEPA (tabular data and laboratory data sheets from Data Binder 1 of 3 for *Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events*, prepared by HDR/EES October 13, 2006; Excel spreadsheet data for LCR compliance period of July – December 2004 received from USEPA). The results of this analysis are summarized in Table 3, where values in bold indicate differences between DCWASA results and results obtained by HDR/EES. These differences involve total sample count, numerical ordering of sample results in the 90th percentile calculations, and/or removal of duplicate compliance sites.

For comparison with the DCWASA results, HDR/EES calculated different values for 90th percentile lead levels and/or the percentage of samples exceeding the AL for the following monitoring periods:

- July – December 1992
- July – December 1993
- January – June 1994
- January – June 1999
- July – December 2003
- January – June 2004
- July – December 2004

For the monitoring period from July to December 1992, DCWASA's 90th percentile lead level does not exceed the AL, whereas the 90th percentile lead level calculated by HDR/EES does exceed the AL. For the monitoring periods July – December 1993 and January – June 1994, the 90th percentile lead levels calculated by HDR/EES are lower than the 90th percentile lead level calculated by DCWASA. Both DCWASA and HDR/EES calculations show that the 90th percentile lead level was greater than the 15-µg/L AL during every monitoring period in years 2001 through 2004.

A review of the July – December 1992 laboratory sampling information found that 30 of the 125 samples exceeded the 15-µg/L action level for lead, but 15 of these 30 samples were not listed in numerical order in DCWASA's 90th percentile calculations. When the sample results were listed in numerical order, and duplicates were removed, the resulting 90th percentile value calculated by HDR/EES was 39 µg/L compared with 15 µg/L reported by DCWASA.

For the January – June 1993 period, the total sample count appeared to be 115 compared with 114 in DCWASA's calculations; however, the 90th percentile result was not affected. For the July – December 1993 period, four sites were originally listed as duplicate samples; however, an additional six sites were found to also have been sampled twice during this period, and one site was sampled three times. DCWASA included all results from these sites in its calculations, and included all duplicate sites in its sample count, for a total sample count of 131. HDR/EES's calculations used only one value from these six additional duplicate addresses and one triplicate (the highest value), for a total sample count of 119, and calculated a lower 90th percentile value than DCWASA. By way of background, USEPA regulations, as clarified in a memorandum dated November 23, 2004 (Grumbles, 2004), now require that all sample results from a system's sampling pool be used in compliance calculations during the LCR monitoring period. If confirmation samples are taken, both the original and confirmation must be used in the 90th percentile calculation.

For the July – December 1997 and July – December 1998 compliance periods, HDR/EES identified a different number of valid compliance samples; however, the calculated 90th percentile result did not differ. For the January – June 1999 period, laboratory sampling reports indicate that 17 first-draw samples had a lead concentration of "<10 ppb"; however, DCWASA's 90th percentile calculations, which converted the data to mg/L, show no samples with a lead concentration of <0.010 mg/L, which is equivalent to <10 ppb. Two samples listed in DCWASA's 90th percentile calculations (0.031 mg/L and 0.055 mg/L) could not be confirmed by the laboratory sample reports. Also, DCWASA's 90th percentile calculations show a total of 106 first-draw samples, but the laboratory summary report indicates only 81 first-draw-samples. Thus, HDR/EES's calculation resulted in a different 90th percentile lead level.

For the remainder of the compliance periods, where differences in either 90th percentile calculations and/or percentage of samples greater than the AL were calculated (July – December 2003; January – June 2004; July – December 2004), the differences were relatively minor and could be attributed to the number of valid samples, 90th percentile calculations, or differences in hard copy tabular data versus Excel spreadsheet data. In all of these compliance periods, both DCWASA and HDR/EES calculated 90th percentile values above the AL.

Table 3. Monitoring program for first-draw lead samples – comparisons of DCWASA and HDR/EES calculations

	DCWASA Results			HDR/EES Results			Reason for Different Results
Monitoring Period	N	90th Percentile Lead (µg/L)	% Samples Lead Conc. > 15 µg/L	N	90th Percentile Lead (µg/L)	% Samples Lead Conc. > 15 µg/L	
Jan – Jun 1992	**129**	18	12	**128**	18	12	One duplicate value removed. 90th percentile result not affected.
Jul – Dec 1992	**125**	**15**	**10**	**122**	**39**	**22**	Three duplicate values removed, plus difference in other valid samples used. 90th percentile result affected.
Jan – Jun 1993	**114**	11	4	**115**	11	4	One additional sample. 90th percentile result not affected.
Jul – Dec 1993	**131**	**37**	**21**	**119**	**29**	**19**	One triplicate and 11 duplicate samples removed, plus difference in total number of valid samples. 90th percentile result affected.
Jan – Jun 1994	114	**22**	**14**	114	**14**	**8**	Five data points not confirmed by laboratory reports. 90th percentile results affected.
Jul – Dec 1994	115	12	7	115	12	7	NA
Jan – Jun 1997	112	6	4	112	6	4	NA
Jul – Dec 1997	**115**	8	4	**114**	8	4	One duplicate value removed. 90th percentile result not affected.
Jul – Dec 1998	**108**	7	4	**100**	7	4	Five duplicates and three raw water samples removed. 90th percentile result not affected.
Jan – Jun 1999	**106**	**5**	**6**	**81**	**<10**	**4**	Difference in total number of valid samples and conversion from ppb to mg/L. 90th percentile result affected.
Jul–Sep 1999	55	12	5	55	12	5	NA
Jul 2000 – Jun 2001	50	8	8	50	8	8	NA
Jul 2000– Jun 2001 (revised calculations - see 2.2.2)	**52**	36	17	**53**	36	17	One additional sample included. 90th percentile result not affected.
Jul 2001 – Jun 2002	53	75	49	53	75	49	NA
Jan – Jun 2003	104	40	26	104	40	26	NA
July – Dec 2003	108	**63**	32	108	**61**	32	Difference in 90th percentile calculation method. 90th percentile result affected.
Jan – Jun 2004	108	**59**	68	108	**58**	68	Difference in 90th percentile calculation method. 90th percentile result affected.
Jul – Dec 2004	**130**	**59**	**31**	**142**	**51**	**28**	Difference in number of valid samples due to difference in hard copy versus Excel spreadsheet data. 90th percentile result affected.

N = Number of samples used in 90th percentile calculation; NA = Not Applicable
Note: ***Bold:*** *Values in bold font indicate differences between HDR/EES and DCWASA calculations.*

2.2.2 LCR 90th Percentile Reassessment

DCWASA met the lead AL of 15 μg/L per the LCR during compliance monitoring from July 1994 through September 1999. As allowed by the LCR, in February 2000 USEPA Region 3 reduced the requirement for LCR tap monitoring to once per year at 50 sites. The DCWASA system continued the reduced monitoring through the July 2001 – June 2002 monitoring period, because DCWASA had reported an LCR 90th percentile value below the AL during the July 2000 – June 2001 LCR monitoring period. In 2004, USEPA Region 3 determined that DCWASA had not included all sample results in its original 90th percentile calculations for the July 2000 to June 2001 period. As listed in Table 3, USEPA Region 3 recalculated the 90th percentile lead level for this monitoring period using all sample results (Rizzo, 2005b). This reassessment showed that the 90th percentile lead level during the July 2000 – June 2001 monitoring period was not 8 µg/L, as originally reported by DCWASA, but it was actually higher at 36 µg/L, which exceeded the AL.

2.3 Second-Draw Lead Results

DCWASA requested that homeowners collect second-draw samples from 1997 through 2004. For the 1997 monitoring periods, second-draw samples were collected and analyzed, but 90th percentile values were not calculated or reported by DCWASA. Second-draw sample results are not used for LCR compliance purposes; however, 90th percentile lead values were calculated for comparison to the AL. HDR/EES reviewed lead concentrations in second-draw samples, checked results against laboratory sample reports, converted hard copy data to digital form, and calculated 90th percentile values. The results of this analysis are summarized in Table 4. In summary, 90th percentile calculations for second-draw samples were greater than 15 µg/L in the July – September 1999 monitoring period, and in every monitoring period from 2001 to 2004.

Differences in results were found for the following monitoring periods: July – December 1998; January – June 1999; January – June 2004; and July – December 2004. These differences, highlighted in bold in Table 4, involve differences in total sample count and/or numerical ordering of sample results in the 90th percentile calculations.

For example, in the July – December 1998 monitoring period, 99 second-draw samples were collected. Therefore, the 90th percentile lead concentration should be equal to the lead concentration of the 89th sample with samples listed in ascending order of lead concentration. This 89th sample is equal to 7.0 µg/L; therefore, the 90th percentile lead concentration is determined to be 7.0 µg/L compared with 6.6 µg/L calculated by DCWASA. DCWASA did not provide details or documentation of the procedure used for calculating the 90th percentile.

For the January – June 1999 period, laboratory sampling reports indicate that 15 second-draw samples had a lead concentration of "<10 ppb"; however, DCWASA's 90th percentile calculations, which converted the data to mg/L, show no samples with a lead concentration of <0.010 mg/L, which is equivalent to <10 ppb. One sample listed in DCWASA's 90th percentile calculations (0.022 mg/L) could not be confirmed by the laboratory sample reports. Also, DCWASA's 90th percentile calculations show a total of 105 second-draw samples, but the laboratory summary report indicates only 79 second-draw samples. Thus, HDR/EES's calculation resulted in a different 90th percentile lead level.

Table 4. Monitoring program for second-draw lead samples – comparisons of DCWASA and HDR/EES calculations

	DCWASA Results			HDR/EES Results			
Monitoring Period	**N**	**90th Percentile Lead Conc. (µg/L)**	**% Samples Lead Conc. > 15 µg/L**	**N**	**90th Percentile Lead Conc. (µg/L)**	**% Samples Lead Conc. > 15 µg/L**	**Reason for Different Results**
Jan – Jun 1997	-	-	-	93	7	5	NA
Jul–Dec 1997	-	-	-	109	7	4	NA
Jul–Dec 1998	**108**	**6.6**	3	**105**	**7**	3	90th percentile calculation
Jan – Jun 1999	**106**	**4**	4	**78**	**<10**	4	Number of valid samples; data conversion from ppb to mg/L; one data point not confirmed by laboratory report
Jul–Sep 1999	55	15	9	55	15	9	NA
Jul 2000–Jun 2001	50	11	6	50	11	6	NA
Jul 2000–Jun 2001 (revised calculations by USEPA Region 3)	-	34	15	58	34	15	NA
Jul 2001–Jun 2002	53	80	46	52	80	46	NA
Jan – Jun 2003	104	21	17	104	21	16	NA
Jul–Dec 2003	108	43	27	108	43	27	NA
Jan – Jun 2004	**108**	**75**	60	**109**	**73**	60	Number of valid samples
Jul–Dec 2004	**130**	**45**	28	**134**	**42**	28	Unknown*

N = Number of samples used in 90th percentile calculation; NA = Not Applicable
Note: DCWASA did not calculate or report second-draw lead concentrations for the two monitoring periods in 1997.
**DCWASA's reported 90th percentiles were presented in a cover letter, but calculation details were not available.*
***Bold:** Values in bold font indicate differences between HDR/EES and DCWASA calculations.*

2.4 Designation of Optimal Corrosion Control Treatment

In July 1997, USEPA Region 3 conditionally designated OCCT as maintenance of a slightly positive Langelier Saturation Index (LSI) through pH adjustment. As a condition of this designation, USEPA Region 3 issued an Administrative Order requiring WA and DCWASA to jointly assess the feasibility of alternative corrosion control treatment including use of sodium hydroxide for pH control, and use of a non-zinc orthophosphate corrosion inhibitor.

Modeling results from the caustic soda study (Malcolm Pirnie Inc., 1998a) indicated that excessive calcium carbonate precipitation would occur if a pH of 8.5 was maintained throughout the year using either lime or caustic soda. The study also concluded that caustic soda would provide some benefits in terms of process control and maintenance requirements. The corrosion inhibitor study (Malcolm Pirnie Inc., 1998b) concluded that zinc orthophosphate would not provide any long-term benefits over orthophosphate in controlling lead levels in the water, and the chemical costs for zinc orthophosphate are approximately twice the chemical costs for phosphoric acid. The corrosion inhibitor study recommended that phosphoric acid be used at a dosage rate of 1.0 mg/L as phosphate (PO_4) if WA decided to use corrosion inhibitors as a lead control strategy.

On February 29, 2000, USEPA Region 3 designated the use of pH adjustment as the OCCT for the systems served by WA. This designation required WA to maintain the highest pH level attainable at the entry points to the distribution system without causing excessive $CaCO_3$ precipitation in the distribution system (USEPA, 2000).

USEPA Region 3 also designated Optimal Water Quality Parameters (OWQP), including an enforceable minimum pH of 7.7±0.3 to be maintained at the entry points to the distribution system and at all tap sample locations. In response to this designation, DCWASA and WA proposed modifications to the OWQP that would allow the minimum finished water pH requirement to change monthly to account for seasonal water quality changes in the Potomac River, as summarized in Table 5. DCWASA and WA also proposed a change to the minimum pH requirement at distribution system sites from 7.7 to 7.0 (source: correspondence from DCWASA and WA, respectively, to USEPA Region 3 on May 1 and May 3, 2000). Two years later, on May 17, 2002, the USEPA revised its designation of OWQP by approving WA's and DCWASA's proposal, and indicated the effective date was retroactive to the monitoring period that began on July 1, 2000.

Table 5. Minimum required pH for distribution system entry points

Month	**Minimum pH**	**Month**	**Minimum pH**	**Month**	**Minimum pH**
January	7.7	May	7.5	September	7.4
February	7.8	June	7.4	October	7.5
March	7.7	July	7.4	November	7.5
April	7.6	August	7.4	December	7.6

Figure 2 shows finished water pH at both distribution system entry points (Dalecarlia and McMillan Water Treatment Plants) and the required minimum pH. The pH at the Dalecarlia entry point has been below the established minimum pH only five times (<1% of data collected) since the OWQP designation became effective July 1, 2000. The pH at the McMillan entry point to the distribution system has been below the established minimum pH only one time (<1% of data collected) since July 1, 2000. Finished water pH levels routinely ranged from about 7.7 up to 8.5 and greater.

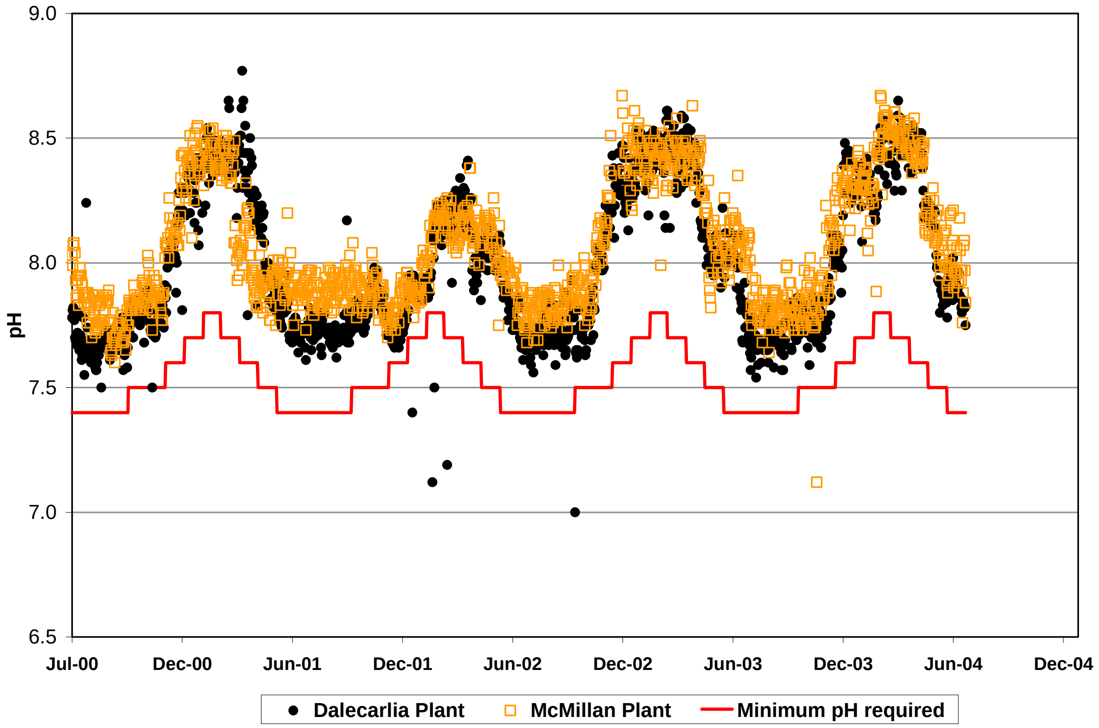


Figure 2. Finished water pH compared to minimum required pH at distribution system entry points (July 1, 2000 – June 30, 2004)

On April 30, 2004, USEPA Region 3 designated use of zinc orthophosphate for partial system application in the 4th High Pressure Zone. This is a designated zone in northwest Washington, D.C. that is hydraulically isolated from the rest of the distribution system (USEPA, 2004b, 2006). On May 28, 2004, USEPA Region 3 modified the April 30, 2004 designation of OCCT to use orthophosphate instead of zinc orthophosphate for the 4th High Pressure Zone.

On August 3, 2004, USEPA Region 3 modified the interim designation of OCCT for WA and DCWASA to consist of application of orthophosphate system-wide, subject to stated conditions and water quality parameters. The interim OCCT designation was slightly modified and clarified on August 20, 2004 and September 8, 2004. USEPA Region 3 stipulated that, during the distribution system passivation period, WA was required to meet a pH range of 7.7 ± 0.3 for finished water leaving both water treatment plants. A goal of 7.7 ± 0.1 was set, though this was not enforceable. For distribution system samples, the same enforceable pH range (7.7 ± 0.3) and non-enforceable pH goal (7.7 ± 0.1) was applied to DCWASA.

Figure 3 shows the average distribution system pH at the 12 OWQP Monitoring Sites in the DCWASA distribution system from July 1, 2000 through October 26, 2004. The 12 OWQP Monitoring Sites were identified by DCWASA in correspondence to USEPA Region 3 dated May 1, 2000. For OWQP monitoring through the date of the USEPA's designation of orthophosphate treatment (July 1, 2000 through August 3, 2004), results show the minimum pH was 7.0, thus demonstrating compliance with the OWQP minimum pH of 7.0. After designation of orthophosphate treatment, OWQP monitoring results were reported through October 26, 2004. Where sufficient data are available, the 3-month running average is shown as a solid line in Figure 3.

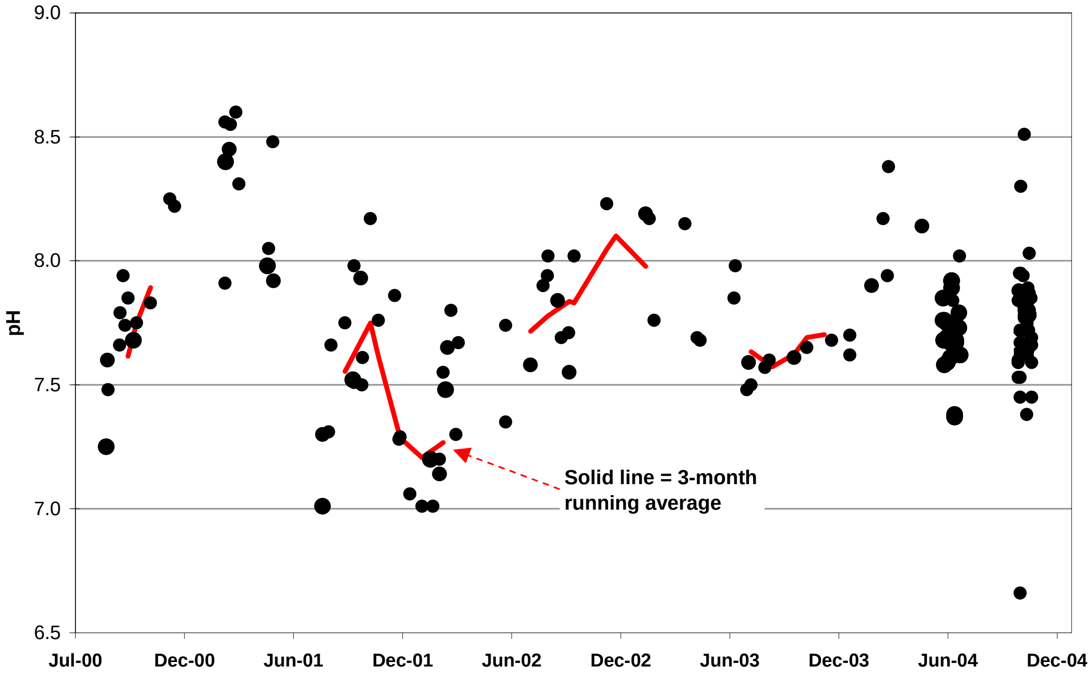


Figure 3. Average distribution system pH measured at different OWQP monitoring sites over different time periods. (July 1, 2000 – October 26, 2004)

2.5 Lead Service Line Replacement Program

Since 2002, DCWASA has been required to replace 7% of the lead service lines on an annual basis due to AL exceedance.

- In September 2003, DCWASA updated its inventory of lead service lines and estimated that of the system's 120,000 service connections, 23,071 were lead service lines. On October 24, 2003, DCWASA reported that during the period October 1, 2002 to September 20, 2003, it had replaced 385 lead service lines through physical replacement including 79 "full" replacements and 306 "partial" replacements (*DCWASA Lead Service Replacement Program Annual Report for 2003*; USEPA Region 3, June 17, 2004).

A partial lead service line replacement (PLSLR) means that something other than the entire length of the service line is replaced (Code of Federal Regulations, Title 40, § 141.84(d)). Title 40 CFR §141.84 requires that a public water system replace the portion of the lead service line owned by the system, but does not require that the system bear the cost of replacing portions of the line that the system does not own.

- On October 8, 2004, DCWASA reported that it had replaced 1,793 lead service lines for the period October 1, 2003 to September 30, 2004 (*DCWASA Lead Service Replacement Program Annual Report for 2004*). No details were provided in the 2004 report on full versus partial replacements.

Full and partial lead service line replacements can disturb protective scales on pipes or connected components and thus cause the release of lead. The full and partial lead service line replacements that have been undertaken by DCWASA are not considered major factors in elevated lead release during LCR compliance monitoring beginning July 2000 because the LSL replacement program did not commence until lead levels were already elevated. DCWASA failed to meet the 90th percentile AL during July 2001 through December 2004, and the LSL replacement program was triggered by failure of DCWASA to meet the 90th percentile AL. Accordingly, LSLs were replaced during the timeframes of October 1, 2002 through September 30, 2003 and October 1, 2003 through September 30, 2004. Further evaluation of DCWASA's LSL replacement program could help determine the extent to which lead service line replacement may have contributed to elevated lead levels at overall or at individual consumers' taps during later periods of exceedance.

Follow-up monitoring required by the LCR at monitoring locations during 2002 through 2004 may have recorded spikes or temporary elevated lead levels due to scale disturbance, possibly exacerbated by cutting and replacement techniques (Wujek, 2005; Boyd et al., 2004). Although not clear, the LCR definitions of Tier 1 sampling sites do not appear to exclude partial LSL replacement sites from continuing as Tier 1 sampling sites (40 §141.86 (3), (i), (ii)). As such, the impact of the PLSLR program could have contributed to elevated lead levels in compliance monitoring data during 2002 through 2004 if the PLSLR sites were used for subsequent compliance monitoring. Without additional information, it is difficult to assess or disregard the effects of PLSLR techniques on elevated lead levels overall or at individual homes where replacements were made. Additional analyses of LSLR sites compared to compliance monitoring sites during 2002 through 2004 would therefore be needed to determine if the LSLR program affected compliance monitoring results at LCR monitoring locations.

3. WATER TREATMENT FACILITIES

This section describes the following:

- Water quality data collected at the two entry points to the distribution system.
- Findings from 1999 and 2003 sanitary surveys of WA-owned facilities.

Data for analysis of water treatment facilities were compiled from daily water quality monitoring results from the Dalecarlia and McMillan plants and from sanitary surveys of WA and DCWASA facilities.

3.1 Water Quality at Distribution System Entry Points

WA collects daily samples for chlorine residual, temperature, pH, and alkalinity at the two entry points to the distribution system located at the Dalecarlia and McMillan Water Treatment Plants. HDR/EES reviewed water quality data from 1998 through mid-2004 with the exception of alkalinity data, which were not available for years 2000 – 2001.

The review of water quality data showed that the two water treatment plants produce water with similar variations in temperature, pH, and alkalinity. As shown in Figure 4, the pH of samples collected at the distribution system entry points generally varied seasonally from 7.7 to 8.5. Figure 5 shows that alkalinity varies widely, typically ranging from about 40 to 100 mg/L as $CaCO_3$ in recent years. Water temperature, shown in Figure 6, varies seasonally from about 35 to 85°F.

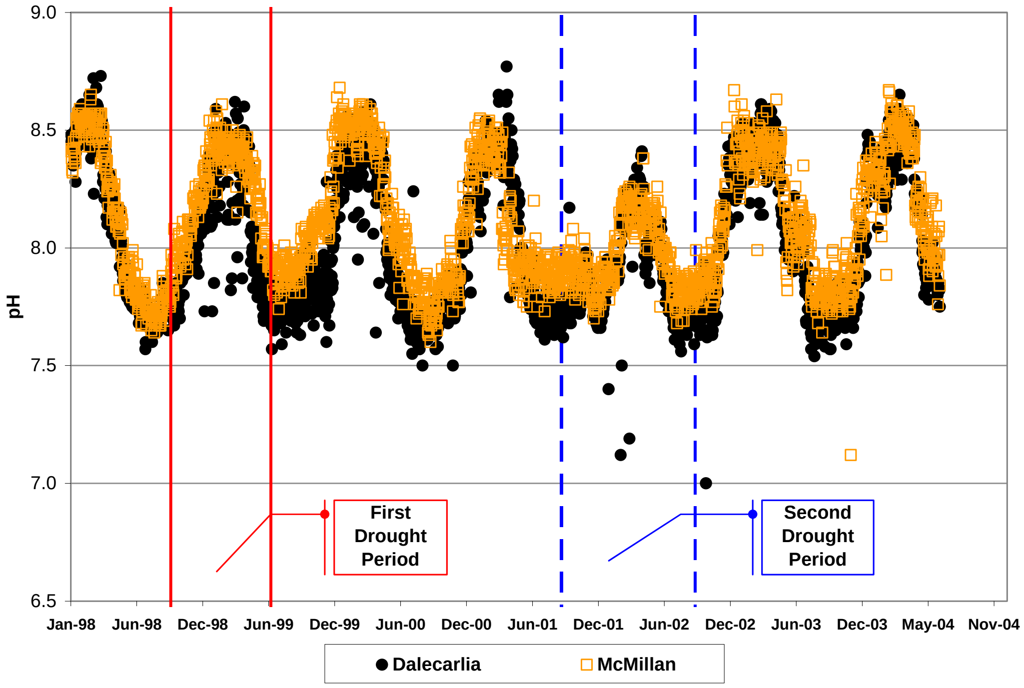


Figure 4. Finished water pH measured at the distribution system entry points (1998 – 2004). Drought periods are designated using solid and dashed lines

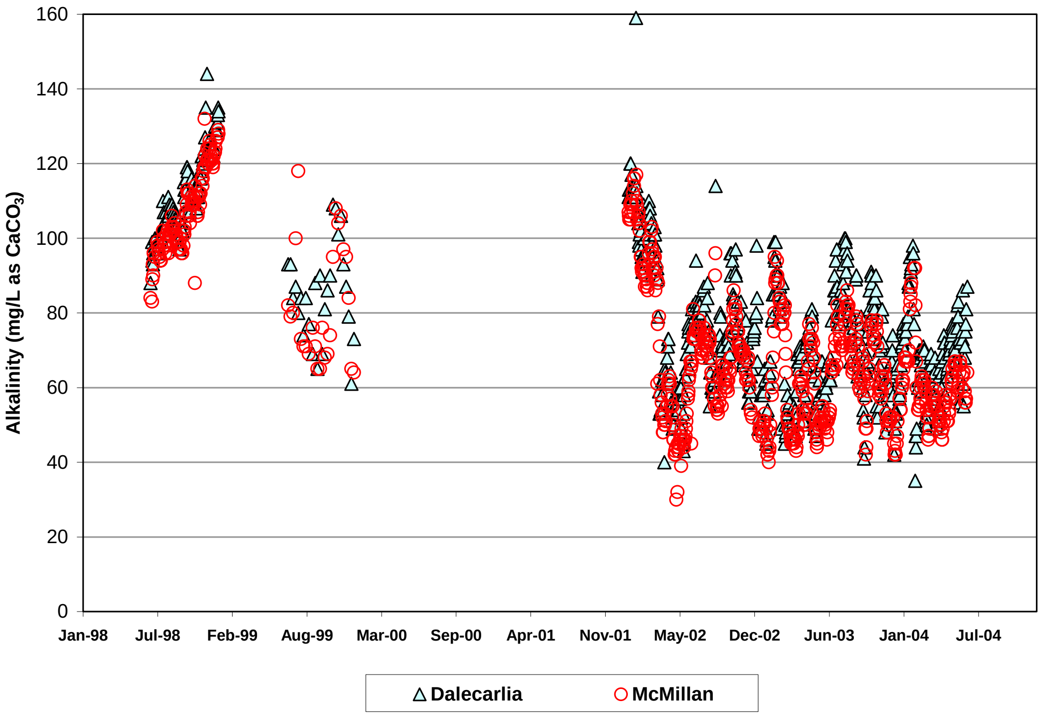


Figure 5. Finished water alkalinity measured at the distribution system entry points (1998 – 2004; no alkalinity data was available for 2000 – 2001)

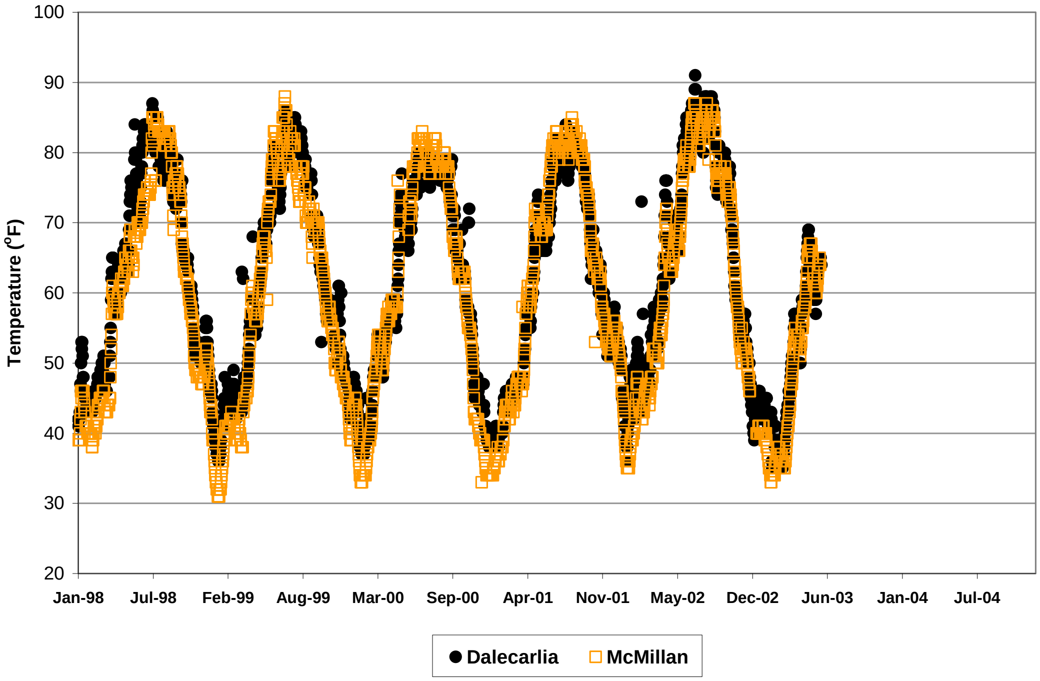


Figure 6. Finished water temperature at distribution system entry points (1998 – 2004)

Figure 7 illustrates chlorine residuals for samples collected at the Dalecarlia and McMillan plants for years 1998 – 2004. These data were provided electronically as Excel spreadsheets. Results were reported as free chlorine prior to November 1, 2000 (disinfectant conversion) and as total chlorine afterward. Prior to the conversion, free chlorine results indicate fluctuations ranging from approximately 2.2 to 3.2 mg/L. After the conversion, chlorine residual increased and total chlorine measurements typically ranged from 3.3 to 3.9 mg/L. Since fall 2003, total chlorine appears to have stabilized in the typical range of 3.5 to 4.0 mg/L.

WA has analyzed the conductivity of untreated water on a monthly basis since 1999. HDR/EES reviewed the available untreated water conductivity data from 1999 through 2002, as presented in Figure 8. Conductivity appears to vary seasonally, increasing in the second half of each year and occurring at lower levels during the spring and early summer. The average conductivity of the source water was 318 micromhos per centimeter (1 micromhos per centimeter = 1 microsiemen per centimeter), and 3-month average values ranged from 238 to 437 micromhos per centimeter.

3.2 Findings from Sanitary Surveys of Water Treatment Facilities

HDR/EES reviewed sanitary surveys of facilities owned by WA. The contents of the sanitary surveys are described below.

- The 1999 sanitary survey documented 73 potential sanitary risks, such as the need for a comprehensive watershed protection program for the Dalecarlia Reservoir, and for updating standard operating procedures for water treatment process operations. At the time of the 2003 survey, 21 of these 73 potential sanitary risks had been fully addressed; 11 had been partially addressed; 7 were no longer applicable to the WA system; and 34 were not addressed.
- The 2003 sanitary survey team identified 37 sanitary deficiencies, including 32 of the 45 sanitary risks identified in the 1999 survey that had not been addressed or only partially addressed. These 37 sanitary deficiencies included development of a comprehensive cross connection control program; development of a comprehensive watershed protection program for the Dalecarlia Reservoir; updating of standard operating procedures for water treatment process operations; an optimization program for each water treatment plant (WTP) including detailed filter evaluations; development of procedures to minimize hydraulic changes in filter operations during backwash; and clearwell modifications to minimize vandalism and pathogen intrusion.

It is difficult to determine whether findings from these sanitary surveys had any influence on tap lead levels. Further examination of pre-1999 sanitary survey data for water treatment facilities may provide more information about events that preceded elevated lead release. Sanitary survey results specific to the distribution system are also discussed in Section 4 and include data prior to 1999.

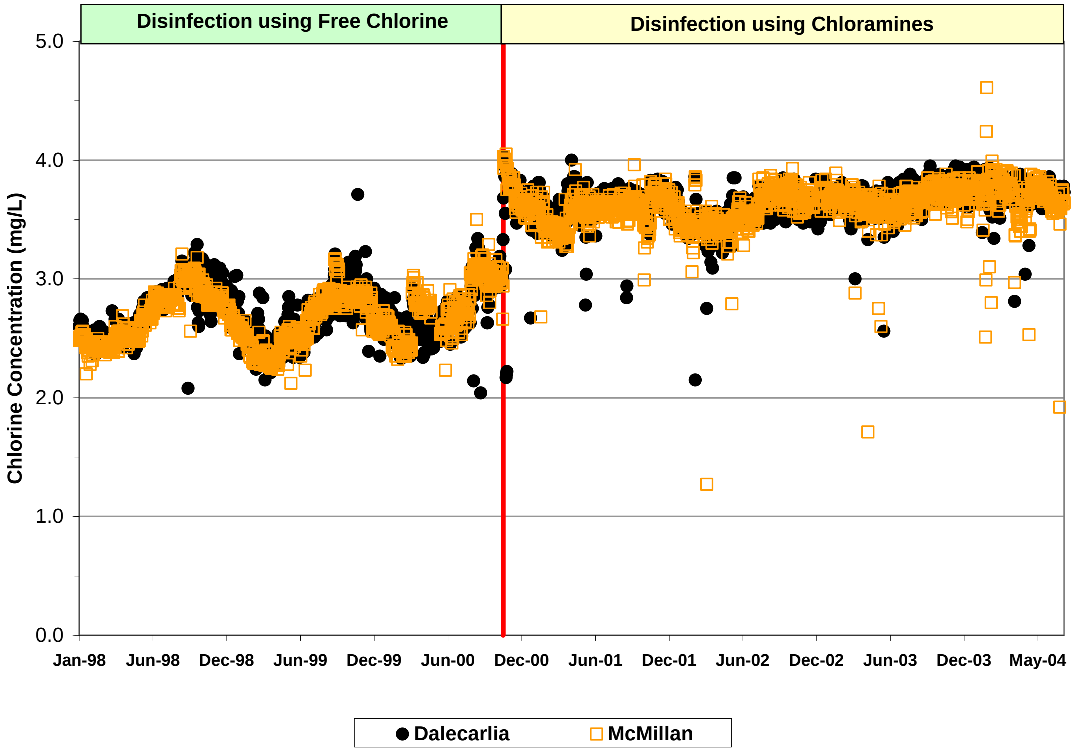


Figure 7. Finished water chlorine residual concentration at distribution system entry points (1998 – 2004)

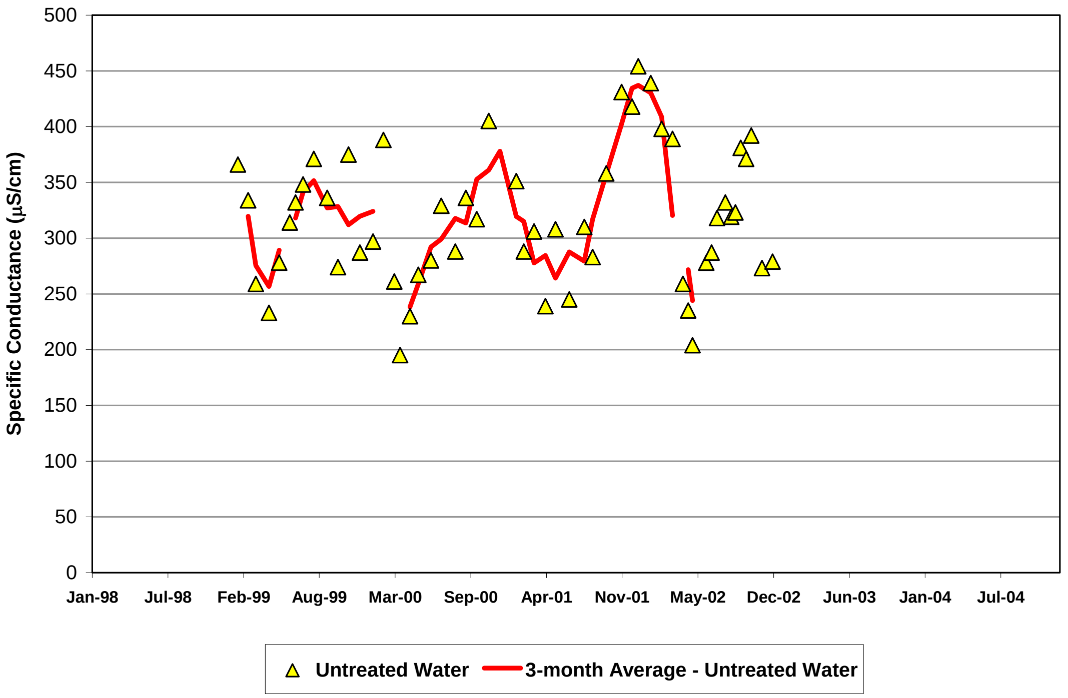


Figure 8. Specific conductance of untreated water (1998 – 2002)

4. DISCUSSION OF DISTRIBUTION SYSTEM CONDITIONS

This section discusses:

- Conditions in the DCWASA distribution system from 1998 – 2004 including water quality trends, lead sources, and other relevant findings from sanitary surveys.

- Available data and information used to identify the major lead sources in or connected to the distribution system.

4.1 Water Quality Trends

Water quality data collected in the distribution system are reported here as daily average parameters for years 1998 through 2004. Data were provided either in digital format or as hard copy laboratory reports or a combination of both. Data were provided in digital format for pH, temperature, free and total chlorine, conductivity, and sampling location for 2001 through 2004. Distribution system pH and alkalinity data were also provided in hard copy reports for years 1998 to 2004. Data and sampling locations included in hard copy reports were transcribed into Excel spreadsheets. Available data and information were then combined into a single spreadsheet. Daily averages were calculated for each parameter based on all available data by sampling location for the years 1998 through 2004. The total number of sampling locations varied by period and parameter; that is, the average value for a given day could have been based on one sampling location or 15 locations, depending on available data. For sampling periods with both hard copy and digital formats available, the digital format was used in this report.

Table 6 summarizes the sources of data and information that are discussed in Sections 4 and 5 of this report. Updated water quality data, sampling dates, and sampling locations are included in the three-ring binders as supplemental information for this final report.

Table 6. Sources of data and information for water quality parameters

Parameter	Hard Copy Reports [a]	Digital Format
pH	8/3/98 – 12/18/00	3/2/01 – 12/30/04
Alkalinity	8/3/98 – 6/30/04	–
Temperature	8/3/98 – 12/18/00	3/2/01 – 12/30/04
Total chlorine	–	3/2/01 – 12/30/04
Conductivity	8/3/98 – 6/30/04	–
ORP	4/5/04 – 7/6/04	4/05/04 – 7/6/04

a. Hard copy reports were transcribed into Excel spreadsheets and merged with data provided in digital format.

4.1.1 pH

Average daily pH and 3-month running average pH values are shown in Figure 9. The line in Figure 9 represents 3-month average pH based on the average of all samples collected during the previous month, the current month, and next month (i.e., the 3-month average for June is the average pH for samples collected in May, June, and July).

Breaks in the 3-month average plot line indicate periods when sufficient data was not available to compute the 3-month average. The average daily pH appears to vary seasonally, peaking in March or April annually except for 2002 and 2003. In late 2001 and early 2002, the distribution system pH was significantly lower than in other years, with 3-month average pH values less than 7.5. In 2003, the peak pH value occurred in early February. The average distribution system pH value for the 1998 through 2004 period was 7.8 with a range of 7.0 to 8.7. It is noteworthy that average pH levels in the distribution system vary widely on a seasonal basis from as low as 7.0 - 7.2 to greater than 8.5.

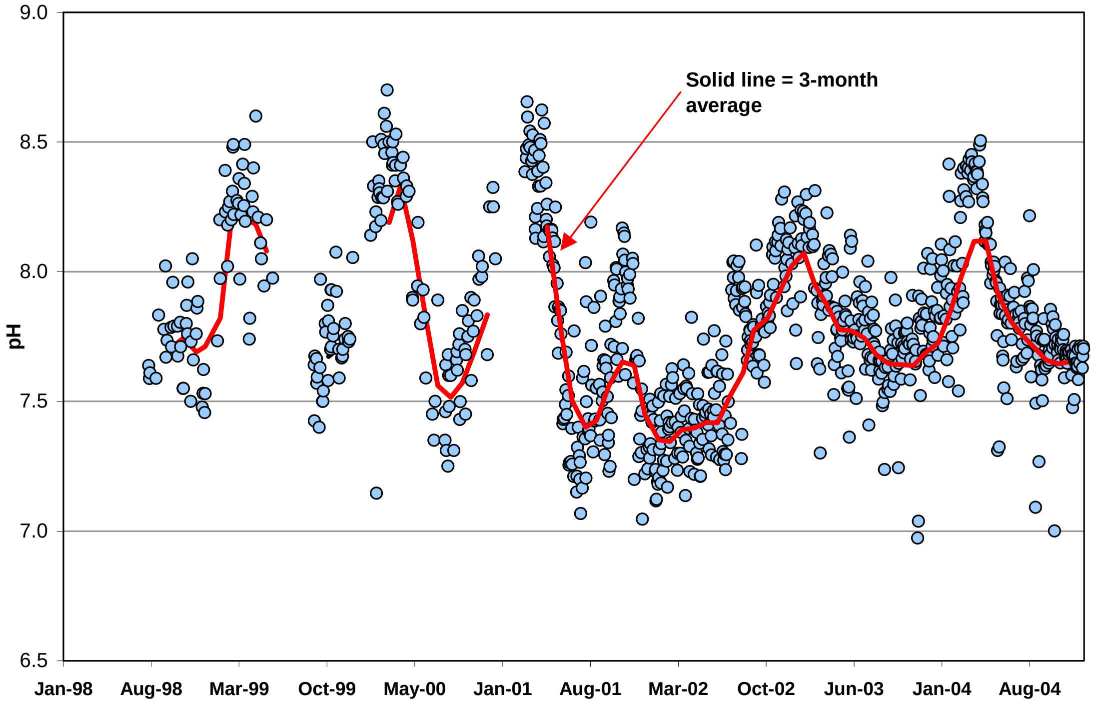


Figure 9. Average daily pH of water samples collected at various sampling sites within the distribution system (1998 – 2004). The 3-month running average pH in the distribution system is shown for comparison.

4.1.2 Alkalinity

As shown in Figure 10, the average daily alkalinity appeared to vary seasonally, peaking during the winter months, until 2003. In 2003, the peak alkalinity level occurred in August. During 2003 and 2004, the distribution system alkalinity decreased overall and yielded an average of 68 mg/L as $CaCO_3$ (note: alkalinity data do not indicate whether measurements were reported as $CaCO_3$ – this has been assumed.) The average distribution system alkalinity for samples collected from 1998 to mid-2004 is 78 mg/L as $CaCO_3$.

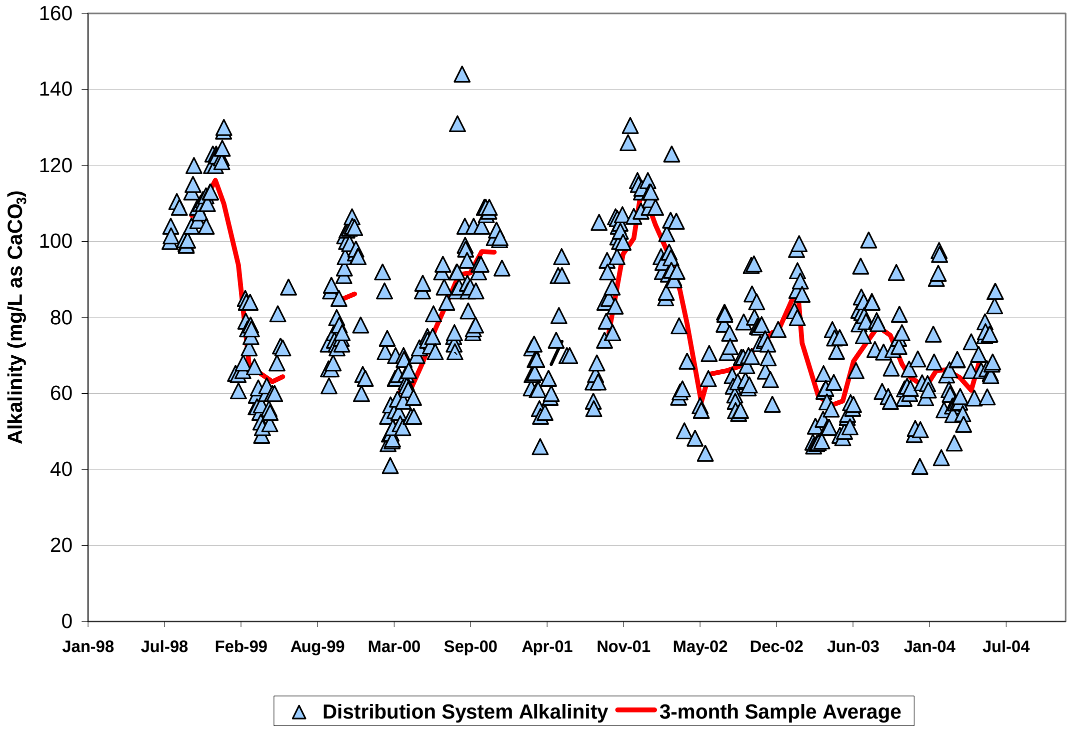


Figure 10. Average daily alkalinity of water samples collected from various sampling sites within the distribution system (1998 – 2004). The 3-month running average alkalinity value in the distribution system is shown for comparison.

Average daily alkalinity and pH values are plotted as a function of time in Figure 11. From the data reported in Figure 11 it is evident that periods of lower alkalinity in the distribution system did not necessarily correspond to lower pH (more acidic) values. For example, in March of 1999 through 2001 and March 2004 there were seasonally associated spikes in pH (to approximately pH 8.5) which corresponded to drops in alkalinity. From April to September 2002, during which the pH remained at a relatively constant value of 7.3, the distribution system alkalinity had decreased from roughly 100 to 60 mg/L as CaCO$_3$. However, the onset of changes in pH and alkalinity did not correspond with one another, suggesting that alkalinity alone was not the principal determinant in the lower pH values that were observed in the distribution system over time.

4.1.3 Temperature

The average daily temperature for water in the distribution system is shown in Figure 12. The temperature varied seasonally, fluctuating from a low of about 40 to 45° F to a high of about 80 to 85° F and peaking in July to August every year.

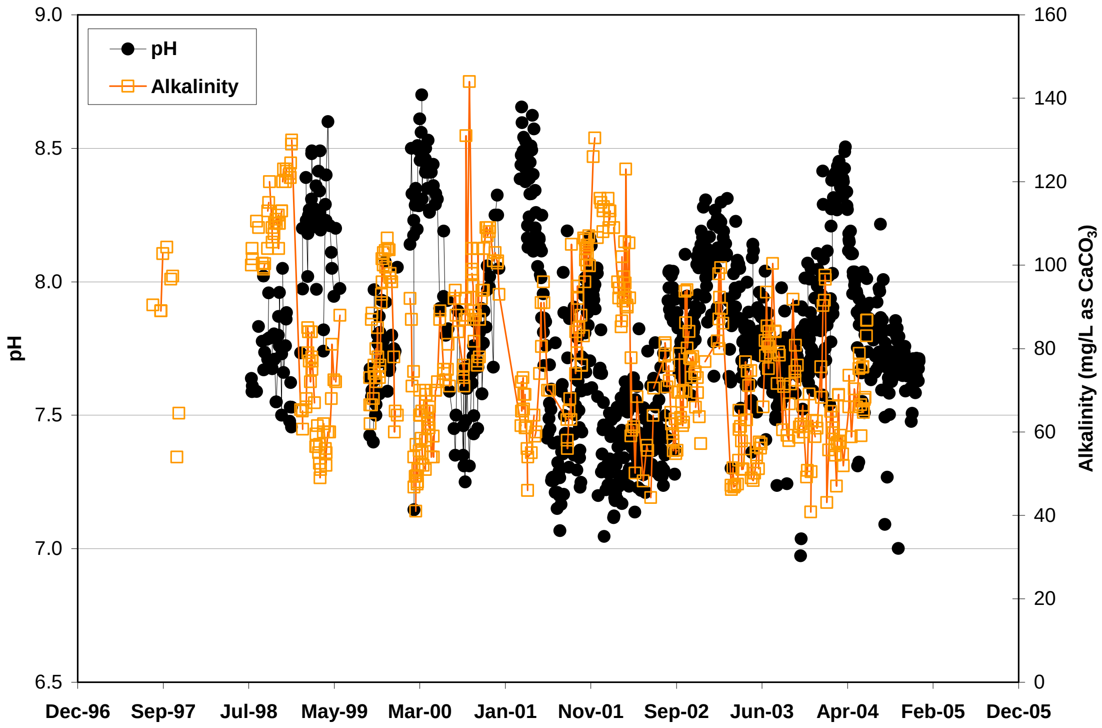


Figure 11. Average daily pH and alkalinity of water samples collected at various sampling sites within the distribution system (1996 – 2004)

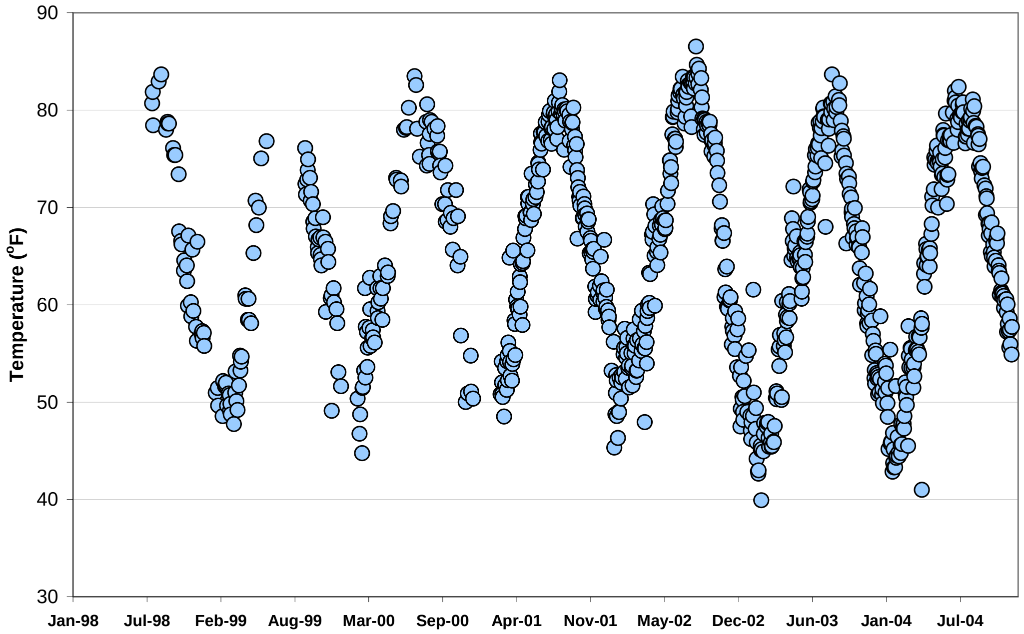


Figure 12. Average daily temperature of water collected from sampling sites within the distribution system (2001 – 2004)

4.1.4 Total Chlorine

WA converted from free chlorine to chloramines as a secondary disinfectant in November 2000. Since implementing the disinfectant conversion, WA has switched periodically from chloramines to free chlorine to address nitrification during the following dates (Rizzo, 2006):

- March 13 to May 13, 2002
- March 10 to April 10, 2003
- April 2 to May 7, 2004

These periods are referred to as temporary disinfectant changes for the purposes of this report. Figure 13 shows average daily total chlorine data for water samples collected in the distribution system in 2001 through 2004. Data collected during the temporary disinfectant changes are highlighted in Figure 13. In general, data indicate that the total chlorine residual in the distribution system during the temporary disinfectant changes was dosed at the same levels as during chloramination.

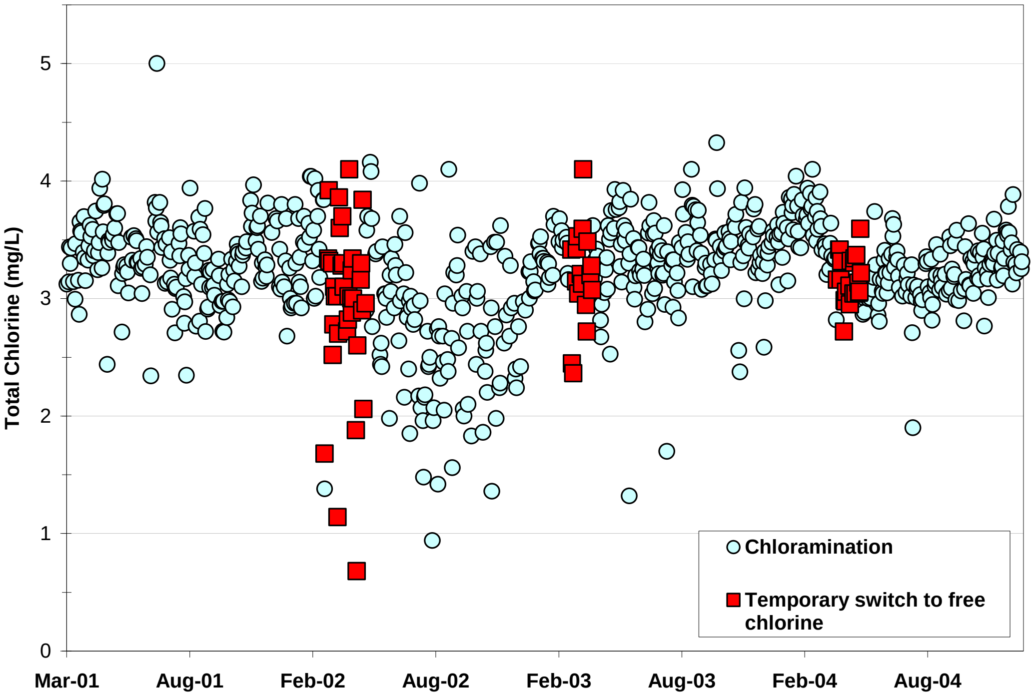


Figure 13. Average daily total chlorine concentration for water samples collected from various sampling sites throughout the distribution system (2001 – 2004).

4.1.5 Conductivity

DCWASA reported values for specific conductance of water in the distribution system at varying intervals and intermittently since 1997. HDR/EES included distribution system data from 1998 through 2004. Available data are shown in Figure 14. Similar to data for untreated water (Figure 8), conductivity in the distribution system appears to vary seasonally, increasing in the second half of each year and occurring at lower levels during the spring and early summer. The average conductivity in the distribution system is 355 micromhos per centimeter, and 3-month average values range from 218 to 495 micromhos per centimeter. The magnitude of these conductivity measurements is comparable to the untreated source water.

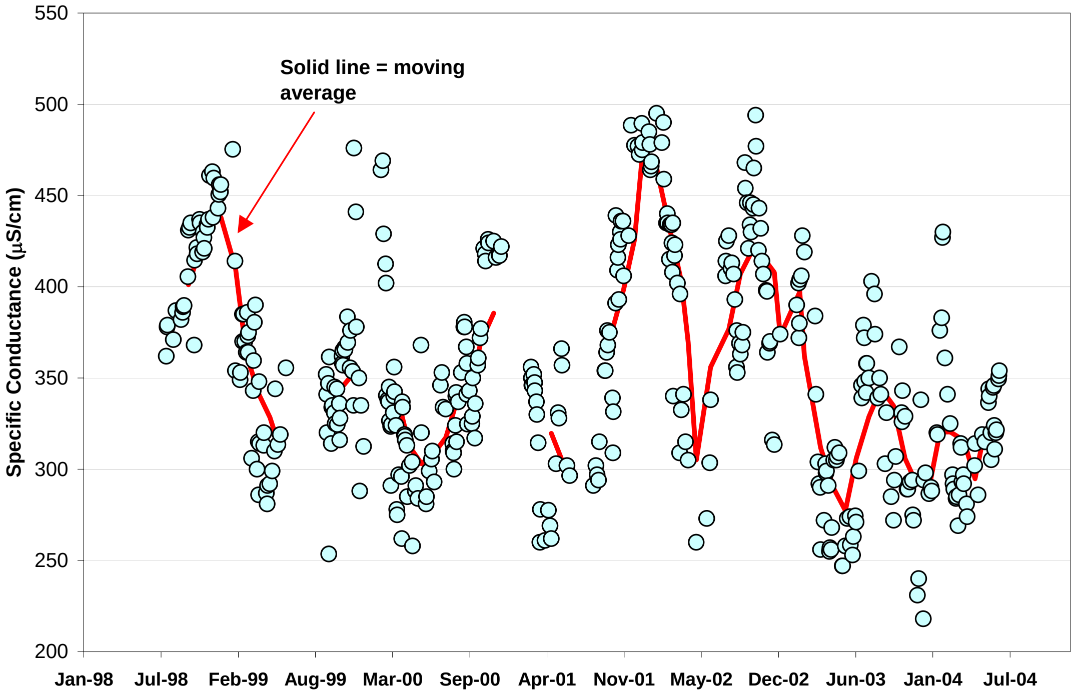


Figure 14. Average daily specific conductance for water samples collected from various sampling sites throughout the distribution system (1998 – 2004). The 3-month running average specific conductance for water in the distribution system is shown for comparison.

4.2 Lead Sources

This section discusses available data and information that were used to identify possible sources of lead in the DCWASA drinking water supply. Data and information collected from the Potomac River were used to assess background lead levels in the natural water source. Additional reports and limited data from samples collected directly from distribution mains were used to assess lead levels in the distribution system. Lead profiling data collected at homes were used to assess the contribution of lead service lines and premise plumbing.

In 2003, DCWASA, with the assistance of Dr. Marc Edwards, developed and implemented a data collection protocol to identify the lead profiles at individual homes. This protocol was utilized at several homes throughout the city to determine the source of lead, the form of the lead (dissolved or particulate), and lead concentrations within the home, the service line, and the water main. Data from 28 lead profiles collected from December 8, 2003 through July 6, 2004 were available for review and are displayed graphically in Appendix A (Moser, 2006). Additional profiles were provided later (Odom, 2006) covering the timeframe since orthophosphate inhibitor was implemented. These additional profiles are included in Appendix A, but have not been analyzed in detail.

4.2.1 Lead Source Evaluation Using Lead Profiling

4.2.1.1 Lead Profiling – Methods and Approach

Twenty-eight lead profiles were developed for 19 homes. The sampling protocol called for an initial sample to be collected in the morning after high water use (samples listed as ‘0’ or ‘00’ on the profiles in Appendix A), followed by a 6 to 8 hour stagnation period after which sequential 1 liter samples were collected at the tap (samples 1 – 20 for example) (Giani et al., 2005a). In addition, some samples were collected after the final sequential sample followed by a period of allowing the water to flow. For example, samples listed as 25+3, etc. on the profiles indicate results from samples collected after the water was allowed to run for 3 minutes after collecting the 25th liter. An additional sample was collected after turning the faucet on and off several times over a 1-minute period, then allowing the water to run 30 seconds prior to collection. Results from these samples are indicated as “X” on the graphs in Appendix A and represent a water hammer condition to evaluate detachment of particulate lead. DCWASA staff removed aerators on taps prior to conducting these lead profiles (Rizzo, 2006c).

Depending on the length and diameter of in-house plumbing and the lead service line at each site, lead results analyzed from selected 1-liter samples drawn from the kitchen tap were correlated to one of the three types of piping based on the corresponding volumes. For example, at one home, the first 4 liters of water withdrawn from the kitchen tap represented the in-house plumbing; the 5th through 9th liters represented the lead service line, and the 10th and additional liters represented the water main. Lead levels were analyzed on liters 1, 2, and 4 (home piping); 5, 7, and 9 (lead service line); and on liters 13, 17, 21, 25, and 45 (the main).

Of the 28 profiles, some were completed at the same houses during one or both disinfectant regimes, and before and after events such as partial lead service line replacement (PLSLR). Additional information is provided in Table 7.

Table 7. Disinfection regime corresponding to when profile data was collected at sites within the DCWASA system

Dates	Disinfection Regime	Additional Information	Number of profiles
Dec 2003 - Apr 1, 2004	Chloramines before temporary disinfectant change	No PLSLR	12
		Repeat after PLSLR	2
Apr 2, 2004 - May 7, 2004	During temporary disinfectant change	During temporary disinfectant change	4
		Repeat of house profiled during chloramines and prior temporary disinfectant change	7
May 18, Jun 28 and Jul 6, 2004	Chloramines after temporary disinfectant change	Chloramines only	1
		Repeat of house profiled during chloramines before temporary disinfectant change	2
TOTAL			**28**

Figure 15 shows a typical profile that has been observed in the DCWASA system. The time period corresponds to chloramine disinfection and is prior to addition of orthophosphate inhibitor. The lead service line shows significantly higher lead levels than both in-home plumbing and the distribution main. Results from profiling are described in Section 5, and additional profiles are supplied both in Section 5 and Appendix A.

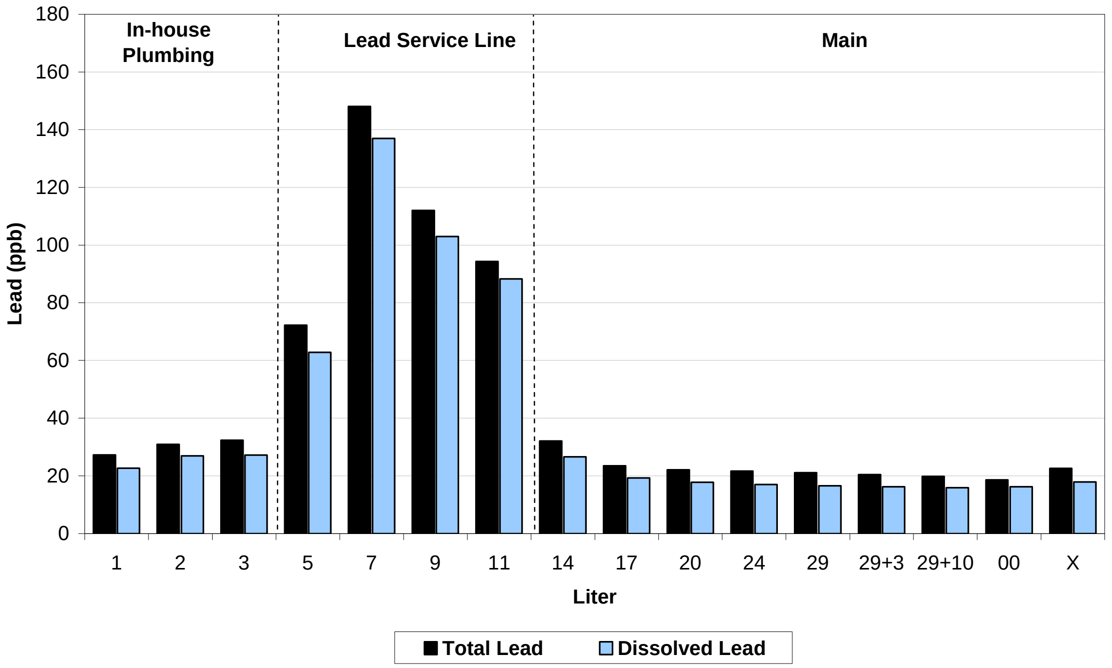


Figure 15. Lead profile for tap water samples from House #8 (sample collected March 9, 2004)

4.2.1.2 Discussion of Results

Profiles from five homes connected to the DCWASA distribution system were discussed by Giani et al. (2005a). The five homes had lead service lines and exceeded the 15-µg/L AL of the LCR within the past 2 years. All of the profiles discussed by Giani et al. (2005a) were collected during a period when chloramines were used for disinfection. One of the homes discussed by Giani et al. (2005a) had lead profiles developed before and after partial replacement of the lead service line. Overall findings from this study indicate that the highest lead concentrations were observed in the water samples that stagnated in the lead service line, compared with water samples representing in-house plumbing and the water main.

Additional lead profiles were collected by DCWASA during chloramination and during the temporary disinfectant change in 2004. Results are shown and discussed in later sections of this report. Similar to the profiles discussed above, these additional profiles collected before and after the temporary disinfectant change indicate that the lead service line contributed the highest lead concentrations at the tap. Over 80% of the profiles collected during these periods (chloramination and temporary disinfectant change) displayed elevated lead levels from the service line portion of the sampling profile.

Using 27 of the 28 profiles shown in Appendix A, an average concentration of lead measured from each lead source (first liter [faucet and associated piping]; premise [remainder of home plumbing]; lead service line; and main) was calculated. Information on which sequential samples represented the first liter, remainder of premise piping, and lead service line was contained in spreadsheets received from the USEPA (Moser, 2006). One set of profile data could not be used because it did not contain information about which samples represented the premise piping, lead service line, and water main.

Table 8 presents the average lead concentration of the first liter (faucet and associated piping), premise (remainder of home plumbing), LSL, and main, and the average mass of lead attributed to these sources. The lead mass data is also represented graphically in Figure 16. The data is presented separately for profiles during the temporary disinfectant change and chloramination. The average mass of lead from the lead service line during the temporary disinfectant change and chloramination were 157 and 470 µg, respectively. In contrast, during the temporary disinfectant change and chloramination the mass of lead in the first-liter sample (faucet and associated piping) was calculated to be 21 and 26 µg, and the remaining home piping was 23 and 72 µg, respectively. The mass of lead was not calculated for main samples since background lead levels in the distribution system were assumed to be < 2 µg/L (Keefer and Giani 2005) and any lead measured from these samples was likely due to pickup of lead from the lead service line.

Results shown in Table 8 and Figure 16 are not exact measurements of the lead contribution of the lead service line, faucet, home piping, and main to lead levels measured at the tap, but merely represent an average of lead released from each of these sources. These results implicate lead service lines as the primary source of lead measured at the tap, compared with lead release from premise plumbing and components (e.g., solder and faucets).

Table 8. Average lead concentration and mass for profiles during the temporary disinfectant change (12 profiles) and chloramination (15 profiles)

<table>
<tr><td colspan="8"><i>Profiles Under the Influence of a Temporary Switch to Free Chlorine</i></td></tr>
<tr><td></td><td colspan="4">Concentration, µg/L</td><td colspan="3">Mass of Lead, µg</td></tr>
<tr><td></td><td>1st Liter</td><td>Premise</td><td>LSL</td><td>Main</td><td>1st Liter</td><td>Premise</td><td>LSL</td></tr>
<tr><td>Average</td><td>21</td><td>13</td><td>22</td><td>6</td><td>21</td><td>23</td><td>157</td></tr>
<tr><td>STD</td><td>31</td><td>18</td><td>18</td><td>4</td><td>31</td><td>22</td><td>141</td></tr>
<tr><td colspan="8"><i>Profiles Under the Influence of Chloramine Disinfection Only</i></td></tr>
<tr><td></td><td colspan="4">Concentration, µg/L</td><td colspan="3">Mass of Lead, µg</td></tr>
<tr><td>Average</td><td>26</td><td>31</td><td>73</td><td>23</td><td>26</td><td>72</td><td>470</td></tr>
<tr><td>STD</td><td>15</td><td>18</td><td>50</td><td>27</td><td>15</td><td>44</td><td>271</td></tr>
</table>

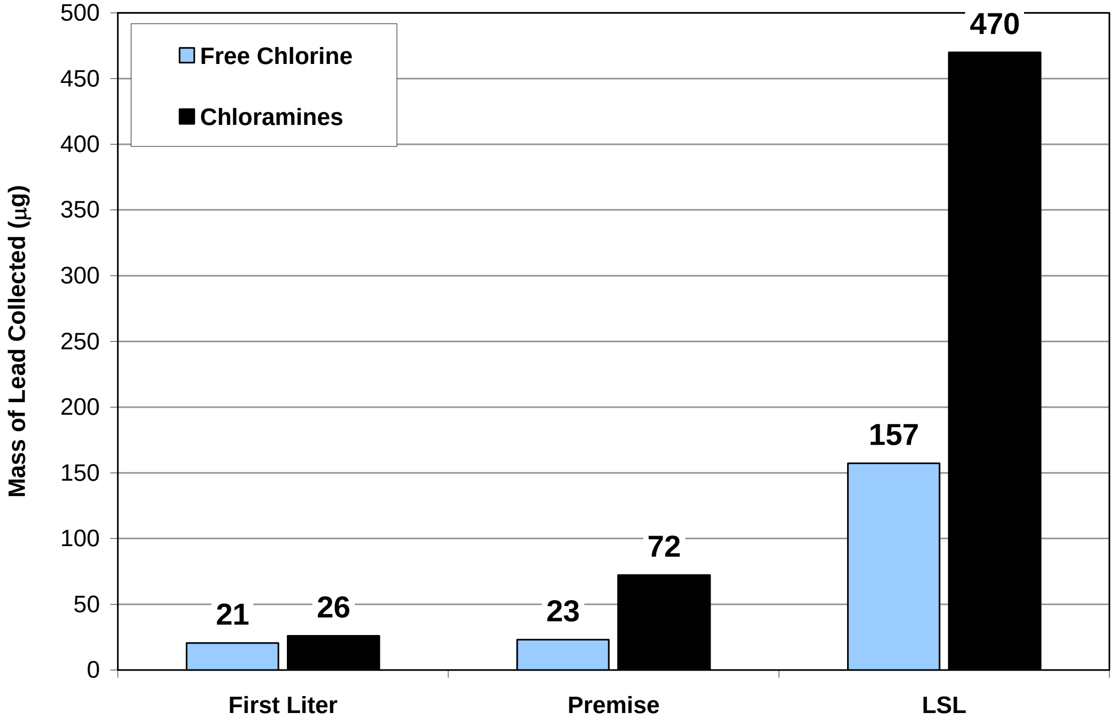


Figure 16. Average mass of lead contributed from various sources for profiles experiencing a temporary switch to free chlorine and those exposed to chloramination disinfection (unadjusted for actual volume of exposure).

4.2.2 Source Water Lead Levels

Lead levels from Potomac River source water are frequently at the ”no-detect” level, and reported as less than 2 µg/L (Keefer and Giani, 2005). For the purposes of this report, ”source water” is defined as raw water from the Potomac River and ”finished water” is defined as treated water leaving the Dalecarlia or McMillan plants. Finished water lead levels are presumably also at the non-detect level. This is difficult to confirm because samples collected at the tap represent water that passed through the mains and was possibly affected by additional lead uptake due to lead solubilization and release from lead service lines and plumbing components.

4.2.3 Distribution Mains

Total lead level samples that are normally considered representative of water entering the lead service line, were collected at the 28 profiles during the temporary disinfectant change and chloramination. Samples included water drawn from the service connection and plumbing and the distribution main in the DCWASA distribution system (labeled as ‘0’ or ‘00’ on the profiles in Appendix A). The lead levels in these samples ranged from 1 to 115 µg/L, with an average total lead value of 16 µg/L. These samples were collected in the morning after flushing the water, according to the procedure described in Giani et al. (2005a), so presumably they represent water from the main. These values were higher than expected based on negligible source and finished water lead levels. It can be difficult to clearly identify lead contributions solely from the distribution main through profiling, even with the appropriate flushing regime that yields samples representative of the distribution main. It is the consultant’s best professional judgment that lead profiling data indicate the likelihood of continued dissolution and pick-up of lead from the service connection including the lead service line and/or other lead sources between the main and the tap and dispersion characteristics of premise piping systems, rather than a notable lead source in the DCWASA water distribution system.

Studies on lead pipes with a range of exposure areas show that the initial rapid rate of lead release is very important to overall lead levels. According to Fick’s Law of Diffusion and assuming an initial negligible lead concentration in water from the main, a large concentration gradient can occur between the LSL and bulk water, thereby leading to exponential rapid lead release, up to equilibrium solubility (Kirmeyer et al., 2000; Van den Hoven et al., 1987). Stagnation time studies of lead pipes and lead-bearing brass components (Lytle and Schock, 2000) also demonstrate rapid initial lead release.

Water samples collected directly from the distribution system provide a more reliable indication of lead levels in the system. Average lead levels in water samples collected in the distribution system are reportedly less than 2 µg/L (Keefer and Giani, 2005). In water quality laboratory reports originating from the WA laboratory, supplied to HDR/EES and characterized as distribution system data, lead data were not generally reported. HDR/EES identified some isolated reports in which lead data were reported. It is not clearly identified in all cases where samples were measured – some are cited as taps and water meters and marked as type ’Sp’, and one is identified as type ‘Dist’ and lists lead level of 0.519 µg/L (June 13, 2001). This limited information, along with the Keefer and Giani report (2005), suggests that water passing through the distribution mains of the DCWASA system contributes minimally to lead levels at the tap.

4.3 Findings from Sanitary Surveys in the Distribution System

HDR/EES reviewed recent sanitary surveys of the DCWASA system. A sanitary survey was completed in 1995 to identify problems and develop recommended mitigation measures associated with bacteriological activity in the distribution system. Survey findings contained 185 recommendations, including a number of sanitary deficiencies at distribution system reservoirs. Follow-up sanitary surveys were conducted in 1996, 1998, and 2002 to document progress on the 185 original recommendations from the 1995 survey, and to identify any additional needs. During this time, the distribution system underwent major rehabilitation including inspection, cleaning, and rehabilitation of storage facilities; cleaning of several large mains; development of a unidirectional flushing program; new operation and maintenance (O&M) manuals; an improved Total Coliform Rule (TCR) sampling plan and sampling sites; clearwell improvements; and staff training. While it is possible that implementation of the unidirectional flushing program and/or main cleaning may have impacted release of dissolved and particulate lead from lead service lines connected to the distribution system, the extent of this impact would be difficult to determine.

5. CAUSATIVE FACTORS OF ELEVATED LEAD LEVELS

The purpose of this section is to identify and describe the evaluation of potential causative factors that contributed to elevated lead levels in the Washington, D.C. drinking water system. As used in this report, the term “causative factors” includes both sources of lead and causative events. The term “causative events” includes historical use of elevated free chlorine concentrations, changes in pH and pH variations, and conversion from elevated free chlorine to chloramines.

HDR/EES reviewed, summarized, and evaluated the following data and information: water quality data; LCR compliance data; sanitary survey reports; corrosion control study reports; correspondence on OCCT; recently completed laboratory studies; lead profile information; and information on DCWASA’s lead service line replacement program. These data, reports, and studies were used to identify and prioritize causes of elevated lead levels in drinking water at consumers’ taps in the DCWASA service area. The following causative factors were considered for this evaluation:

- Lead release from piping systems and other lead-bearing materials
- Historical use of elevated free chlorine concentrations
- Distribution system pH levels and pH variations
- Conversion from elevated free chlorine to chloramines for final disinfection
- Water quality characteristics in the distribution system
- Galvanic corrosion of lead service lines
- Effect of grounding currents on lead-bearing components
- City-wide meter replacement program
- Drought conditions and effects of corrosivity on DCWASA water

Section 5.1 discusses the integration of the potential causative factors listed above and draws conclusions about the combination of factors that contributed to lead release at consumers’ taps in Washington, D.C. prior to the 2000 to 2004 LCR compliance monitoring. Section 5.2 provides background information regarding oxidation reduction potential, lead scales, theory, and ongoing research pertaining to the combination of factors that can contribute to lead release in drinking water systems. Sections 5.3 through 5.11 provide separate evaluations of the causative factors listed above.

5.1 Combination of Factors Contributed to Lead Release

A combination of factors – not a single source or a single causative event – contributed to the problematic release of lead in water at consumers' taps in the DCWASA system. Figure 1 in Section 1 illustrates the timeline of events beginning in 1992 that highlights operations and regulatory compliance decisions, 90th percentile lead levels, shifts in disinfectants and pH, coliform events, and other key dates and related activities. Table 9 provides a summary of decisions by USEPA pertaining to OCCT and actions by DCWASA. The primary source of lead release was attributed to the presence of lead service lines in the DCWASA service area. Since the mid-1990s, three notable occurrences took place in the DCWASA system that likely contributed to elevated lead releases during 2000 through 2004: (1) historical use of elevated free chlorine concentrations; (2) low pH operating levels and pH variations; and (3) conversion from elevated free chlorine to chloramines. These three notable occurrences pertained to water quality changes and water quality conditions. Sources of lead and water quality occurrences are summarized below.

Table 9. Summary of Optimal Corrosion Control Treatment (OCCT) Decisions and Actions

Date	OCCT Decisions and Actions
July 16, 1997	USEPA Region 3 designates OCCT as maintenance of a slightly positive Langelier Saturation Index (LSI) through pH adjustment. USEPA Region 3 issues an Administrative Order (AO) that the above designation is subject to the condition that WA and DCWASA jointly assess feasibility of alternate corrosion control treatment including pH adjustment with sodium hydroxide and addition of a non-zinc orthophosphate corrosion inhibitor.
February 29, 2000	As a result of the corrosion control feasibility studies, USEPA Region 3 designated pH adjustment as the OCCT for the WA distribution systems. This designation required that: • WA maintain highest pH attainable (without causing calcium carbonate precipitation) at entry points to the distribution system. • A minimum pH of 7.7 maintained at entry points to the distribution system and at all tap samples within the distribution system.
May 1, 2000	DCWASA proposed modifications to the OCCT designation set by USEPA Region 3. The modifications included the following: • Allow minimum pH requirement to change monthly to account for seasonal changes (maximum of 7.8 in February and minimum of 7.4 in June –September) • Reduce minimum pH in the distribution system from 7.7 to 7.0
May 17, 2002	USEPA revised its designation of OCCT to accept the modifications proposed by DCWASA and WA on May 1, 2000 noting that the decision had been verbally agreed to in 2000. The designation was made effective from the LCR monitoring period which began on July 1, 2000.
April 30, 2004	USEPA Region 3 designated use of zinc orthophosphate for partial system application in the 4th High Pressure Zone (a hydraulically isolated zone of the DCWASA distribution system).
May 28, 2004	USEPA Region 3 modified the April 30, 2004 designation to use orthophosphate, instead of zinc orthophosphate.
August 3, 2004 (modified Aug. 7, Sept. 20, 2004)	USEPA Region 3 modified the interim designation of OCCT to consist of the following: • Application of orthophosphate system-wide • Interim WQP o WA pH 7.7 +/- 0.3 (entry points) o DCWASA pH 7.7 +/- 0.3 (distribution system) • WQP Goal o WA pH 7.7 +/- 0.1 (entry points) o DCWASA pH 7.7 +/- 0.1 (distribution system)

5.1.1 Sources of Lead

The primary source of lead release was attributed to the presence of LSLs in the DCWASA service area. Faucets, lead-tin solder, and other home plumbing components likely contributed, but were not the major sources of lead release in samples collected at consumers' taps.

5.1.2 Historical Use of Elevated Free Chlorine

The first notable water quality change occurred in the mid-1990s when the concentration of residual free chlorine was increased to the range of 2.2 to 3.2 mg/L, which was implemented for the purpose of controlling coliform occurrence in the water distribution system. These relatively high free chlorine concentrations likely facilitated the formation of Pb (IV) scales in the form of lead dioxide (PbO_2) in lead service pipes. Lead dioxide scales generally exhibit relatively low lead solubility under normal ranges of pH and alkalinity in public water systems when compared to Pb (II) compounds. Lead scales on the interior of lead service lines are likely comprised of various forms of lead, including both Pb (II) and Pb (IV), and the chemical composition of the scales likely changes with varying water quality conditions.

5.1.3 Low pH Operating Levels and pH Variations

The second notable occurrence pertains to the fluctuating and low pH of the water supply in the DCWASA system. pH of the water is an important factor in the control of lead solubility. The pH of the distributed water in Washington, D.C. exhibited seasonal variations that fluctuated from approximately 7.0 to 8.9 during 1992 to 2004. pH levels at the lower end of this range would not be considered optimal for lead corrosion control based on the conventional understanding of lead solubility per the LCR, which assumes that the dominant form of scales is Pb (II). In Washington, D.C., however, and as stated above, relatively high free chlorine concentrations during the mid-1990s likely facilitated the formation of Pb (IV) as the dominant scale, which exhibits relatively low lead solubility at the lower pH levels experienced in the DCWASA system.

5.1.4 Conversion from Elevated Free Chlorine to Chloramines

The third notable water quality change occurred when WA converted the residual disinfectant from free chlorine to chloramines beginning November 1, 2000. The residual disinfectant conversion was implemented for the purpose of lowering disinfection byproducts to meet new regulatory requirements. This conversion facilitated a reduction in ORP to a range that favors the predominance of Pb (II) scales. Pb (II) species generally are highly influenced by low and fluctuating pH levels. This conversion from free chlorine to chloramines likely facilitated the release of lead in water while operating at low, fluctuating pH conditions. Lead release may also have been impacted when the minimum pH requirements at entry points and distribution sites were lowered at the request of WA and DCWASA and the request was approved by USEPA Region 3 effective July 1, 2000.

5.2 Lead Scales and Solubility

As previously mentioned, it is likely that the lead scales on the interior of lead service lines are comprised of various forms of lead, including both Pb (II) and Pb (IV). It is also likely that the chemical composition of these scales changes with varying water quality conditions. Pb (II) scales, the dominant form of scales expected in public water systems based on conventional understanding per the LCR, are highly influenced by low and fluctuating pH levels. Pb (IV) scales, which can be formed in unique situations such as elevated free chlorine concentrations, exhibit relatively low lead solubility under normal ranges of pH and alkalinity in public water systems when compared with Pb (II) scales.

5.2.1 Oxidation Reduction Potential (ORP)

Oxidation reduction potential (ORP) is defined as the potential required to transfer electrons from an oxidant to a reductant (Symons et al., 2000). Recent research on lead corrosion shows that the bulk ORP value of water can increase in the presence of free chlorine compared to chloramines. Lytle and Schock (2005b) noted that where lead-bearing materials are present, Pb (IV) in the form of PbO_2 is “associated with waters of persistently high ORP”. The authors note that the high ORP is a result of maintaining a sufficiently high level of free chlorine residual whether due to low oxidant demand or where high free chlorine concentrations are necessary to address microbiological concerns in the distribution system. In lead precipitation experiments, Lytle and Schock (2005b) found that at a maximum free chlorine residual dose of 3 mg/L, the ORP was approximately 0.942 V corrected to the Standard Hydrogen Electrode (SHE), and when the study concluded and free chlorine was 0 mg/L, ORP was approximately 0.440V (SHE). Vasquez et al. (2006) evaluated several different source waters under different treatment regimes and found ORP was higher in waters with free chlorine (0.9 V) than in waters with chloramines (0.68 V). Switzer et al. (2006) measured equilibrium potentials for free chlorine and monochloramine resulting in ORP of 1.02 V and 0.65 V, respectively. Research also demonstrates that ORP can influence the dominant lead species, (Lytle and Schock, 2005b; Switzer et al., 2006). Further, ORP is influenced by several factors including the following: pH (Lytle and Schock, 2005b), temperature (Vasquez et al., 2006), chlorine residual and concentration (Vasquez et al., 2006), and dissolved oxygen concentration (Khanal et al., 2003).

Some ORP data were available for the DCWASA distribution system. Hydrant sampling was conducted by DCWASA in 2004 at sites within the 4th High Pressure Zone, a designated zone in northwest Washington, D.C. that is hydraulically isolated from the rest of the distribution system (USEPA, 2004b, 2006). Hydrant sampling was conducted during a period of temporary disinfectant change to free chlorine (April 1, 2004 through May 7, 2004) and after converting back to chloramines (Odom, 2006b). Only two hydrant sites were sampled during both periods. However, all data from the 4th High Pressure Zone hydrant sampling, even where only one value was available, are plotted in Figure 17.

Information was not available for this study regarding whether the ORP data in Figure 17 were reported as field data or if the ORP values were corrected to the standard hydrogen electrode (SHE). Furthermore, the limited available data were evaluated for the purpose of characterizing a relative difference in ORP during chlorination compared to chloramination in the DCWASA system. The limited data appear to show higher ORP values during a temporary change in disinfectant to free chlorine compared to the subsequent return to use of chloramines in the DCWASA system.

As demonstrated in Figure 17, ORP levels were at least 150 mV higher during the temporary change to free chlorine compared to periods when chloramines were in use. During the temporary disinfectant change to free chlorine, the measured ORP values were ≥ 650 mV. After the temporary disinfectant change, and a return to chloramines, most sites showed an ORP in the 450 to 500 mV range.

Theoretical calculations of ORP based on other available parameters may also be helpful in understanding historical redox conditions in the DCWASA service area

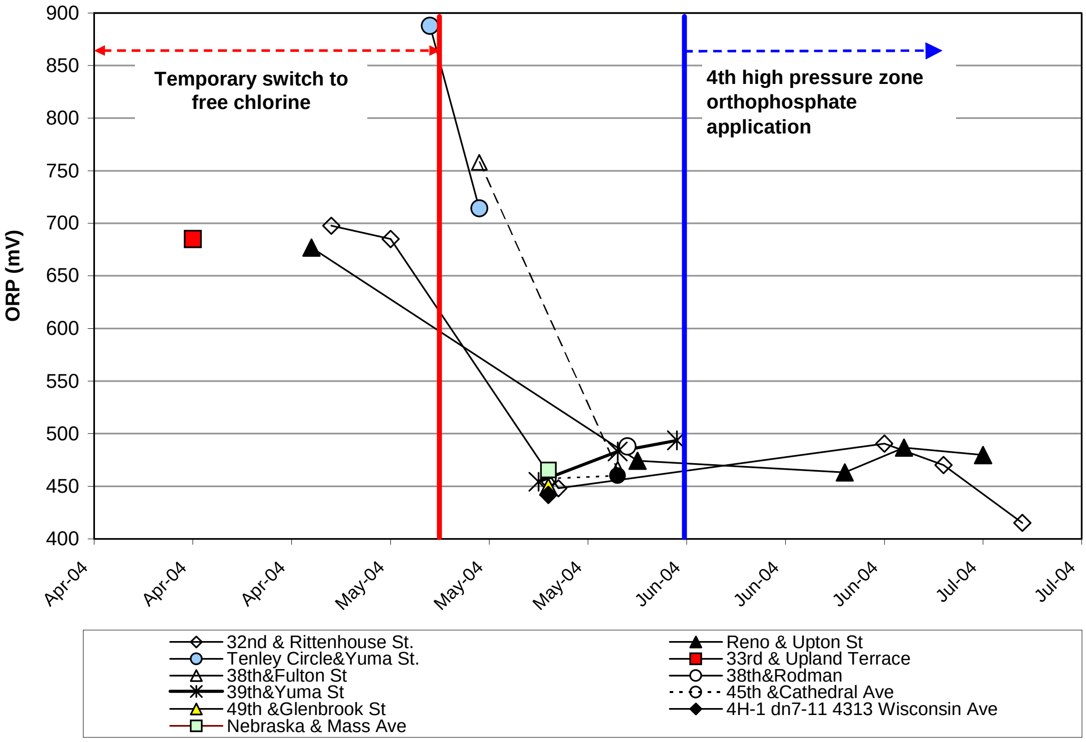


Figure 17. ORP (mV) vs. date for the 4th High Pressure Zone during the temporary disinfectant change (April 2, 2004 through May 7, 2004) and after the temporary disinfectant change

For the data shown in Figure 17, there are no applicable lead data from the same hydrant samples to correlate before, during, and after the temporary disinfectant change. However, system-wide data collected before, during, and after the temporary disinfectant change exists in the form of both LCR data (Table 3) and lead profiles from houses (Section 5 and Appendix A). The LCR data in Table 3, although somewhat limited, indicates that lead levels measured during the temporary disinfectant change using free chlorine were lower than lead levels measured afterward during routine chloramination in the DCWASA system.

The lead profile data in Section 5.6 for periods before and during the temporary disinfectant change generally show a reduction in lead release during the temporary disinfectant change. As shown in Figure 17, ORP data plotted after June 1, 2004 were collected in the 4th High Pressure Zone during the partial system orthophosphate application (Appendix A). Lead levels from samples collected after orthophosphate application were not evaluated as part of this report. However, current LCR compliance results suggest that lead levels have been effectively reduced by the addition of orthophosphate inhibitor to the water supply (DCWASA, 2005, 2006).

5.2.2 Lead Scales

Control of lead in drinking water generally has been presumed to be controlled by Pb (II) solids that form on lead-containing materials. However, more recent evaluations of scale materials on lead service lines have indicated the presence of Pb (IV) in the form of PbO_2 solids under certain distributed water quality conditions (Schock et al., 2001; Schock and Giani, 2004; Schock, 2005; Schock et al., 2005). In theory, Pb (IV) solids have a lower solubility than Pb (II) carbonate solids and will be stable in waters that have a high ORP. Evidence has been gathered that Pb (IV) is formed under high ORP conditions but it becomes unstable once ORP is lowered, and that the absence of a high free chlorine residual (such as during chloramination) allows the occurrence of lower ORPs (Schock and Giani, 2004; Lytle and Schock, 2005b). Therefore, by switching to chloramines, the ORP of the water may be lowered, allowing Pb (IV) solids to decompose via several possible reaction pathways. During the transformation, lead levels in the water may increase and the more soluble Pb (II) carbonate species may be formed as described by Schock and Giani (2004).

Figure 18 illustrates the electrochemical (EC) potential-pH diagram that is helpful in understanding lead release events (Schock and Giani, 2004; Lytle and Schock, 2005b). The numbered boxes show how the sequence of treatment changes formed the PbO_2 passivating film associated with Pb (IV) during elevated free chlorine concentrations, and then destabilized the Pb (IV) species when the pipe scales reverted to the predominance of Pb (II) species during subsequent chloramination in the DCWASA system.

Point 1 (Figure 18) corresponds to a period in the early 1990s of low free chlorine residual, Pb (II) scale dominance, and lead release problems. Initiation of high free chlorine residuals and flushing in 1994 moved the system chemistry to the predominance of Pb (IV) scales (PbO_2) as shown by Point 2. The change to chloramines for secondary disinfection on November 1, 2000 moved the ORP back into approximately the area of Point 3, thus causing further lead species transformation back to Pb (II) and an increase in lead levels at the tap. The DCWASA LCR lead level results described previously and the reported analyses of scales on excavated lead service lines support this mechanism. Lead service lines that were excavated prior to the conversion to chloramination (i.e., lead pipes exposed to water when elevated levels of free chlorine were used) primarily contained Pb (IV) compounds (plattnerite and scrutinyite) with only traces of Pb (II) compounds (cerussite and hydrocerussite) (Schock and Giani, 2004; Schock, 2005).

As demonstrated by theory and recent research, free chlorine residual levels can impact lead release depending on the dominant form of lead, i.e., Pb (IV) or Pb (II), in scales on lead service pipes. Additional data and discussion regarding free chlorine residual levels in the DCWASA distribution system are presented in Section 5.4.

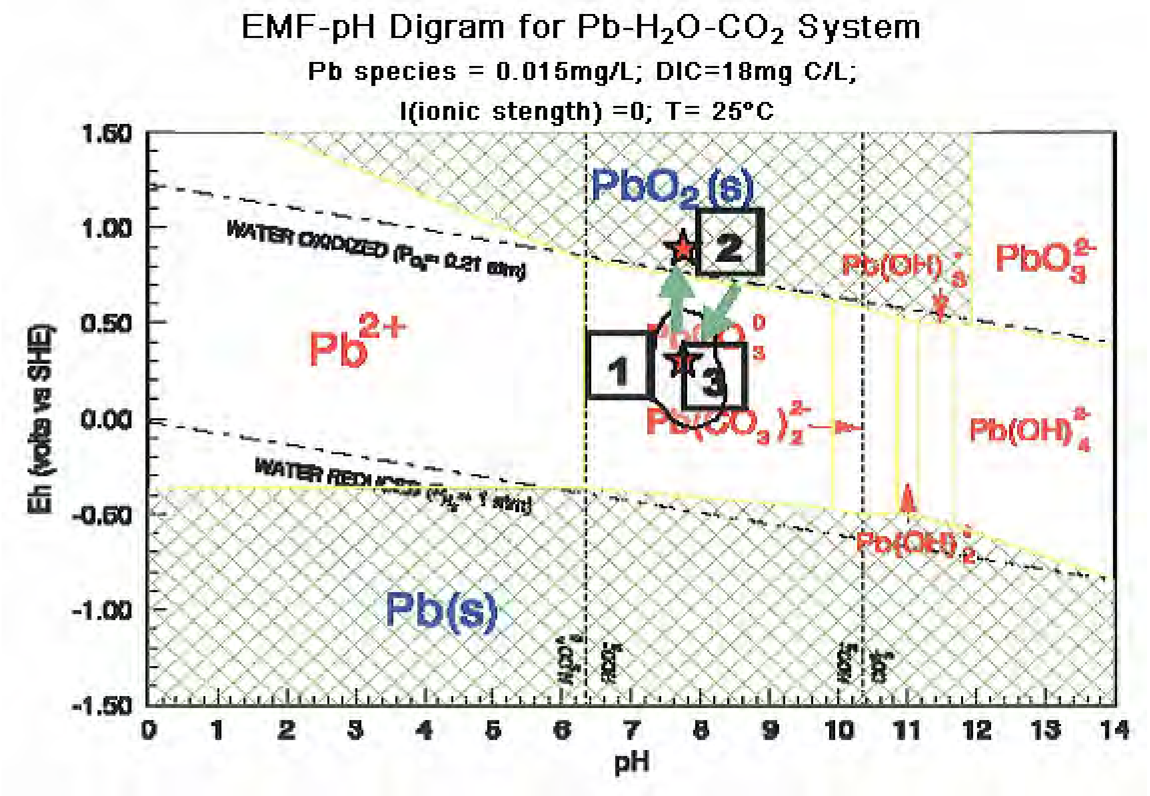


Figure 18. Potential-pH diagram for the lead system corresponding to DC WASA water (Schock and Giani, 2004)

Conditions of low free chlorine residuals during the early 1990s and chloramines since 2000 suggest the possibility of similar ORP values in the DCWASA system and similarly the predominance of Pb (II) scales as proposed by Schock and Giani (2004). The solubility of Pb (II) is reasonably well established and believed much higher than Pb (IV) over the normal range of pH in public water systems. However, current understanding of Pb (IV) solubility is largely based on solubility models, and additional data gaps exist with respect to alkalinity/DIC and other water quality parameters.

The effectiveness of orthophosphate in conditions whereby Pb (IV) scales are the predominant species is not well understood. If an orthophosphate inhibitor had been added to the DCWASA water supply for corrosion control in the early 1990s when Pb (II) was presumably dominant, it may have been more effective as OCCT (than pH adjustment) before, during, and following the switch from free chlorine to chloramines for final disinfection. If orthophosphate treatment was used as OCCT in the early 1990s, DCWASA may have avoided elevated lead levels in customers' taps. However, if an orthophosphate inhibitor had been added to the DCWASA water supply during the mid to late 1990s when elevated free chlorine was added to the water supply, then it is not known how effective the orthophosphate inhibitor would have been compared to pH adjustment. Currently, little information is available regarding the effectiveness of orthophosphate treatment under Pb (IV) scale conditions, which are presumed to have been dominant due to elevated free chlorine concentrations before the disinfectant switch. Accordingly, this topic could benefit from further research to better understand the impact of orthophosphate inhibitor under different disinfectant, ORP, and scale conditions.

It is important to point out that changing from free chlorine to chloramine disinfection does not always correspond to elevated lead release. Pb (IV) formation is associated with systems that have high ORP, which can be caused by a variety of mechanisms including high free chlorine dosages (Schock and Giani, 2004). Free chlorine residual levels are discussed further in Section 5.4.

Systems that do not have a history of such high ORP conditions may have maintained a Pb (II) scale and never have been in a Pb (IV) regime. The accepted corrosion control mechanism, based on Pb (II) and optimal corrosion control including pH adjustments, would have been effective in those systems, and possibly not altered by chloramines, since Pb (II) scale was already dominant as the passivating layer. Follow-on work with other systems that have had disinfectant changes in the presence of Pb (IV) scales could provide additional insight with regard to understanding the complex interrelationship of lead scales and water quality.

5.2.3 Theory and Ongoing Research Pertaining to Pb (IV)

Theory and developing research on tetravalent lead can potentially improve understanding of the treatment changes and conditions that influence lead scales and lead release. As more information becomes available, it may further explain the causative factors for the increased lead release in the DCWASA system.

According to recent studies (Lytle and Schock, 2005a; Switzer et al., 2006), transformation of elemental lead, Pb(0), to divalent lead, Pb (II), occurs in both chloraminated and chlorinated water systems. The transformation of existing Pb (II) to Pb (IV) is not well understood beyond the presence and absence of free chlorine and the corresponding measured ORP values. Similarly, details of the dissolution and precipitation behavior of Pb (IV) are still not well understood (Lytle and Schock, 2005b; Switzer et al., 2006).

Solubility differences between Pb (II) and Pb (IV) may also be important. The solubility constants (Ksp) of PbO_2, $Pb_3(OH)_2(CO_3)_2$ (hydrocerrussite) and $PbCO_3$ (cerussite) at 10^{-66}, $10^{-18.8}$, and 10^{-13}, respectively (Switzer et al., 2006; Marani et al., 1995) allow calculations that show PbO_2 is much less soluble than Pb (II) solids. This comparison of solubility constants indicates that PbO_2 potentially dissolves less readily than the two Pb (II) mineral forms. Although speciation and solubility data for all of the various Pb (II) and Pb (IV) compounds that may be involved is scarce, models suggest that Pb (IV) solubility is generally lower than Pb (II) solubility (Schock et al., 2001).

In the Schock et al. (2001) study, lead scales from pipes in the Cincinnati distribution system were examined using several mineral characterization techniques. The study identified a passivating film consisting of polymorphs of Pb (IV) in the form of PbO_2 on all of the pipe samples. In the study, solubility vs. pH relationships were developed for PbO_2 using three values of the Gibb's free energy of formation obtained from the literature. The solubility-pH relationships all predict that PbO_2 has a much lower solubility than Pb (II) in the form of $PbCO_3$ and that the solubility of Pb (IV) in the form of PbO_2 decreases with decreasing pH. The authors note that the solubility–pH minimization trend for Pb (IV) is the opposite of that for Pb (II); i.e., Pb (IV) solubility tends to decrease with decreasing pH, approaching a minimum solubility at approximately pH 4. Based on these models, a change to a much more soluble form of lead (i.e., Pb (II) mineral forms) offers a potential explanation for the sustained increase in lead release in the DCWASA system. The earlier predominance of the relatively low solubility Pb (IV) could explain why the lower pH range did not adversely affect lead levels in that time period, as might have been expected based on Pb (II) solubility. Under these assumptions, the switch to chloramines in November 2000 and the reduction in minimum allowable distribution system pH are conditions that would likely not have been optimal for the Pb (II) scales.

5.3 Lead Release from Piping Systems and Other Lead-Bearing Materials

Lead from piping can potentially be released in either the soluble or particulate form. While particulate lead is important and can contribute to elevated lead in some instances, soluble lead appears to be the primary form of lead measured in DCWASA tap samples. The predominant source of soluble lead in the DCWASA tap samples is attributed to lead service lines. Other components, fittings and piping materials made of lead-bearing materials such as brass, bronze and solder potentially can contribute to elevated lead levels at consumers' taps. These sources of lead are discussed below.

5.3.1 Soluble Lead from Piping

Figure 19 was developed by evaluating a specific sample from the lead profile data (Section 5.2 and Appendix A) for every available profile and calculating the average particulate and dissolved lead concentrations as a percentage of total lead. This process was repeated for the 5th through 9th liters, which correspond to the lead service line. Profiles were restricted to those collected during disinfection with chloramines from December 8, 2003 through March 31, 2004. Profiles at sites with partial lead service line replacements were omitted due to erratic results from particulate lead spikes. The results listed below clearly show the predominance of soluble lead over particulate lead.

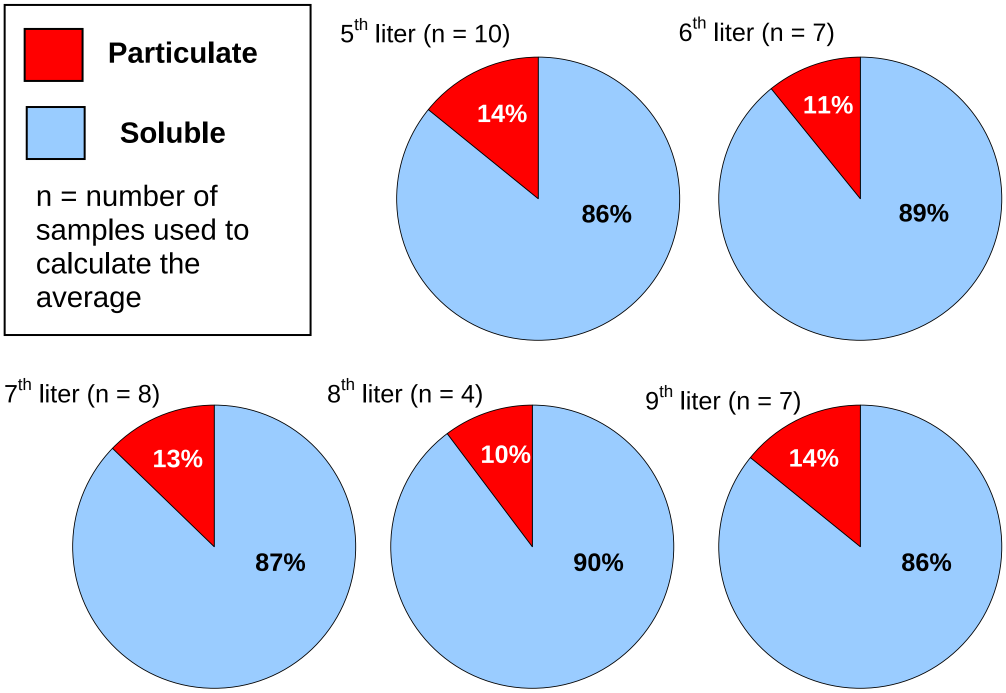


Figure 19. Average contribution of dissolved and particulate lead as a percentage of the total lead concentration in distribution system water samples (December 2003 through March 2004)

Figure 19 shows soluble lead in the approximate range of 86 to 90 percent based on HDR/EES's review of available lead profiles. This observation is consistent with findings reported by Giani et al. (2005a) regarding lead levels in unfiltered and filtered samples collected for lead profiling at five homes in the DCWASA system. In the study, the filtered sample represents the amount of dissolved lead in the water, while the unfiltered sample represents the total lead in the water. The conclusions of the Giani et al. (2005a) study were that the majority of elevated lead concentrations were due to dissolved lead, and the lead profiles presented, similar to HDR/EES's review, show that approximately 85 to 90 percent of the total lead was in dissolved form. Based on these findings, the detachment of lead particles from piping systems does not appear to be a significant cause of elevated lead levels in the DCWASA system. Both the profiles evaluated by HDR/EES and in the Giani study suggest that soluble lead is much more important in terms of relative contribution to lead levels at consumers' taps.

5.3.2 Particulate Lead from Piping

Based on the results from the lead profiles, it appears that particulate lead release from piping systems is not a significant system-wide problem with respect to samples collected for LCR compliance, but may occur intermittently due to site-specific conditions and hydraulics.

The potential exists for lead particles (scale) to be disturbed and to detach from pipe surfaces including in-house plumbing and lead service lines. Release of particulate lead could be caused by a variety of factors, including hydraulic scour, physical disturbance such as vibration (which could occur during service line replacement), chemical changes in the water that might exacerbate release of particulate lead, and/or site-specific flow, piping, and environmental conditions.

There are limited situations where high-particulate lead was measured in the DCWASA service area. For example, the first sample from Profile #22, as illustrated in Figure 20 shows a relatively high concentration of total lead. Typically, the majority of total lead is in dissolved form. However, high-particulate lead may be observed occasionally as related to site-specific piping, water use patterns, or high flow rate during sample collection that can cause shearing of particulate lead from the piping system.

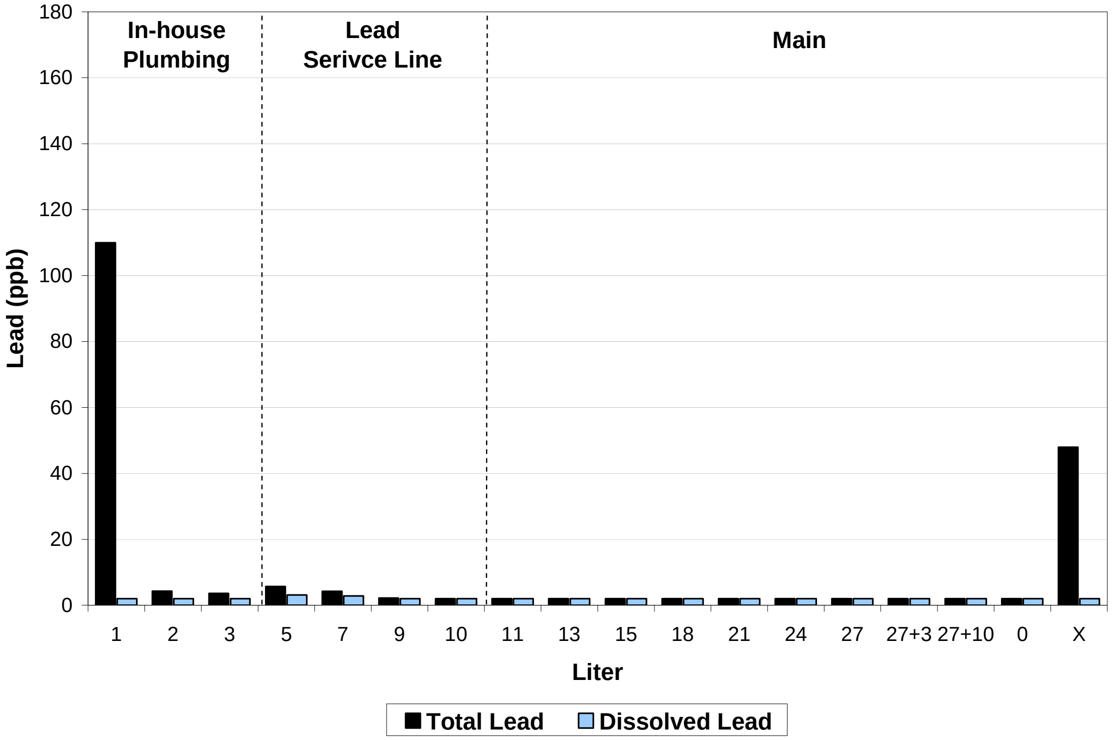


Figure 20. Lead profile data for House #22 (sample collected April 30, 2004) under conditions of water hammer that cause high levels of particulate lead release (Particulate Lead = Total Lead – Soluble Lead)

The majority of the samples collected to evaluate water hammer effects (Sample 'X' in Appendix A) exhibited high dissolved lead levels, i.e., little particulate lead. However, at Profiles #16, #17, #22, #23 (Appendix A) the water hammer condition likely dislodged particulate lead, indicating that occurrence of particulate lead may be related to hydraulic conditions.

In a report to USEPA Region 3, Dr. Marc Edwards (Edwards, 2003) noted that LCR sampling results may not take into consideration use of filtration devices on kitchen taps and that sampling procedures at these sites should be checked and documented. Since

2004, DCWASA's LCR sampling instructions have directed homeowners to remove water filters from the sampling tap before taking the sample or to collect the sample from a tap which does not have a filter (Rizzo, 2004).

A common configuration for faucets includes an aerator attached to the end of the faucet. This aerator may serve as a trap for particulate lead that has been released from piping systems. During June 2002 (the last month of the July 1, 2001 through June 30, 2002 compliance monitoring period), customers were instructed to remove the aerators prior to collecting samples. The instructions for removing the devices prior to sampling continued through the January 1 to June 30, 2003 monitoring period. From July 1 to December 31, 2003, customers were instructed to leave the aerators in for lead monitoring samples, and this procedure is still in effect (Smith, 2006). The impact of leaving the aerator in place during sampling is that lead particles may be trapped in the aerator rather than included in the sample. If these particles build up, they could provide an additional lead source to the water. A sample drawn for compliance purposes from a tap where the aerator is still in place would more likely represent human exposure conditions.

With respect to particulate lead release from lead service lines, it is possible that partial replacement of lead service lines could result in release of lead scale and cause a corresponding increase in particulate lead measured at the tap. Since 2002, DCWASA has been required to replace 7% of the lead service lines on an annual basis due to lead action level exceedances. Wujek (2005) reported that particles in the remaining partial lead service line piping were disturbed and released to the water column for a temporary period of time after the replacement. While partial lead service line replacements may have negatively impacted lead levels in the DCWASA system (i.e., due to the possible release of lead particles to the water column) the extent of the impact cannot be determined based on current information.

Table 10 summarizes the evaluation of data and information regarding lead release from piping systems.

Table 10. Summary evaluation of data and information – lead release from piping systems

Data and Information Considered	Evaluation of Data and Information as Pertaining to this Possible Cause
HDR/EES analysis of DCWASA Lead Profiles in Excel spreadsheet obtained from USEPA Region 3.	Lead service line piping is the predominant source of lead measured at the tap. Approximately 86-90% of total lead is in the soluble form.
Giani et al., 2005a.	Approximately 85-90% (calculated by HDR/EES from graphs in paper) of the total lead is in the soluble form. Particulate lead occurs in limited instances, likely related to site-specific piping and water use, and/or flow rate during sample collection.

5.3.3 Faucets, Solder, and Other Home Plumbing

Typical plumbing and premise piping in residences and buildings can consist of lead-bearing materials such as brass or bronze fittings and components and tin-lead solder used to join copper piping. End-use devices such as faucets and plumbing fixtures also can contain lead-bearing materials that can contribute to lead uptake in the water. Prior to the promulgation of the Lead and Copper Rule in 1991, lead solder and flux used to join copper premise piping and faucets and fixtures 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, 1991).

Giani et al. (2005a) evaluated the primary source of lead in the DCWASA system using lead profile data collected at five homes. This study indicated that the highest lead concentrations were observed in the water samples which stagnated in the lead service line compared with water samples representing in-house plumbing and the water main. Results from additional lead profiles also indicate that the lead service line contributes the highest lead concentrations at the tap. Over 80% of the profiles available for review in this study displayed elevated lead levels from the service line portion of the sampling. An estimate of the relative mass of lead from faucets, solder, and other home plumbing indicates that approximately 24 μg of lead may be associated with the first liter sample (faucet and associated piping) and 50 μg of lead may be associated with the remaining home piping and components prior to the lead service line. In the DCWASA system, as in other analogous systems, whether lead service lines are present or not, other plumbing components can still potentially result in exceedance of the LCR 90th percentile AL at the consumers tap (Boyd et al., 2006b).

As discussed previously in Section 4.2, the average mass of lead release attributed to the LSL was 157 μg during the temporary disinfectant change to free chlorine and 470 μg during routine chloramination (Table 8). It is important to reiterate that these values are based on average mass loadings of each source in the system. Based on results from Giani et al. (2005a) and estimates of the mass loading of lead from various portions of home and service piping, it appears that while faucets, solder, and other home plumbing contribute to lead levels measured at the tap, they are not the predominant source of lead in the DCWASA system. Table 11 contains a summary of the data and information related to faucets, solder, and other home plumbing.

Table 11. Summary evaluation of data and information – faucets, solder, and other home plumbing

Data and Information Considered	Evaluation of Data and Information Pertaining to this Possible Cause
Giani et al., 2005a. HDR/EES analysis of DCWASA Lead Profiles in Excel spreadsheet obtained from USEPA Region 3.	Faucets, solder, and home piping contribute to lead at the tap, but they are not the predominant source.

5.3.4 Distribution Mains

As discussed in Section 4.2, the distribution mains and other system components connected to the DCWASA distribution system are not likely a major contributing source of lead at the tap. While review of the lead profile data contained numerous instances where thoroughly flushed samples from the water main still contain measurable lead, it is likely, as explained in Section 4.2, that rapid release of lead from the lead service line and/or home systems or dispersion and mixing characteristics of the premise plumbing caused the higher than expected results in the flushed samples. Even without acknowledging the rapid release from LSLs or other components, the results from water in the main are still notably lower in the lead profiles than in the lead service lines. Table 12 summarizes the evaluation of data and information regarding water in distribution mains.

Table 12. Summary evaluation of data and information – water in distribution mains

Data and Information Considered	Evaluation of Data and Information Pertaining to this Possible Cause
Keefer and Giani, 2005	Lead levels in the distribution system are low, typically <2 μg/L.
Lead Profiles	Lead in flushed samples and in samples targeting the main is often detectable and many samples are greater than 10 μg/L, likely due to rapid release of lead from service and premise piping.

5.4 Impacts of Historical Use of Elevated Free Chlorine Concentrations

Chlorine residual data from the DCWASA entry points and distribution system locations were provided for review. Data from the points of entry to the distribution system include free chlorine measurements from January 1992 to October 2000, and total chlorine residual measurements from November 2000 (after the switch to chloramines) through December 2004. These data are shown in Figure 21.

To address Total Coliform Rule (TCR) problems in the distribution system in the early to mid-1990s the free chlorine residual was increased from approximately 1 – 2 mg/L to 3 – 4 mg/L at entry points to the distribution system. As discussed previously in Section 5.2, this lower chlorine residual period was thought to correspond to low ORP and predominance of Pb (II) scales (Schock and Giani, 2004). Figure 21 shows the periods of lower free chlorine residual at the distribution system entry points in the early 1990s when lead release problems were first observed. Corresponding free chlorine levels within the distribution system prior to 1998 were not available for review, but it can be assumed that residual levels within the distribution system would have been lower than those measured at the point of entry. The 1994 –1995 period of elevated free chlorine residuals, and up until chloramination in November of 2000, were periods of low lead release – thought to correspond to higher ORP and Pb (IV) scale dominance (Schock and Giani, 2004).

Figure 22 shows free chlorine residual levels measured within the distribution system from 1998 through 2004, which captures the period before and after the switch to chloramines. Prior to the switch to chloramines and during the period of low lead release (i.e., 1994 to October of 2000), free chlorine levels were approximately 2 mg/L within the distribution system. As expected, after the switch to chloramines, the free chlorine residual decreased to very low levels (i.e., typically less than 0.5 mg/L), aside from seasonal switches back to free chlorine for nitrification control/prevention purposes. The decrease in free chlorine levels associated with the switch to chloramination may have created ORP conditions that were similar to the early 1990s when free chlorine residuals were also relatively low and Pb (II) scales were thought to be dominant. As described previously in Section 5.2, the operating pH was also reduced in July of 2000, which may have contributed further to Pb (II) release under chloraminating conditions.

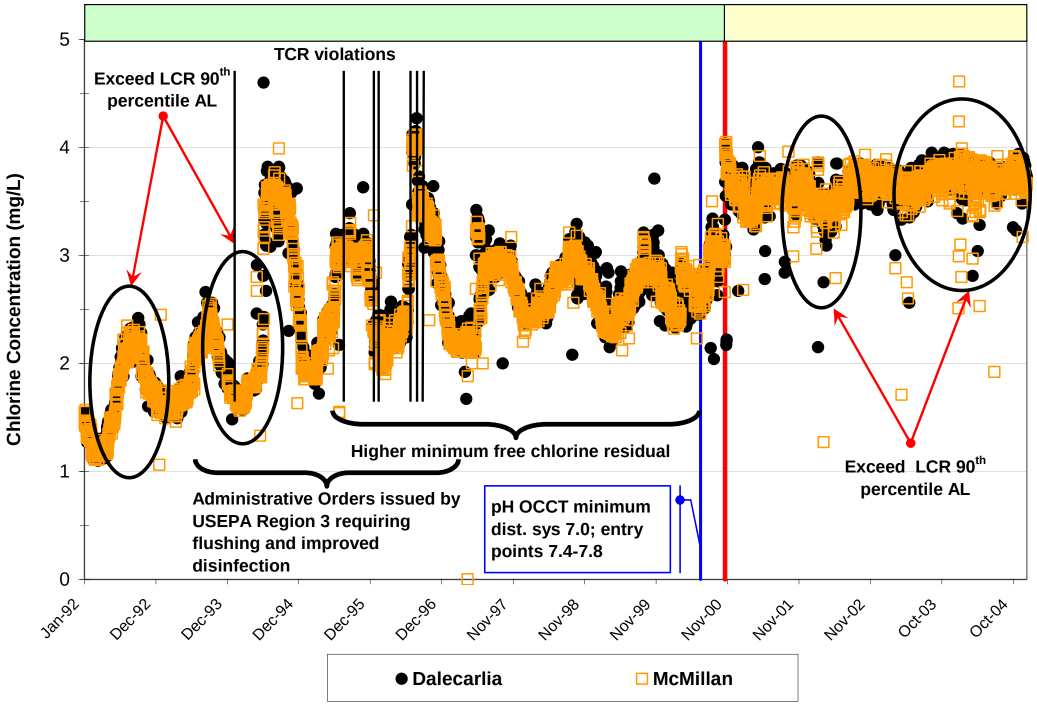


Figure 21. Free and total chlorine residual as a function of time illustrating periods of lower chlorine residuals at the distribution system entry points in the early 1990s (January 1992 through December 2004)

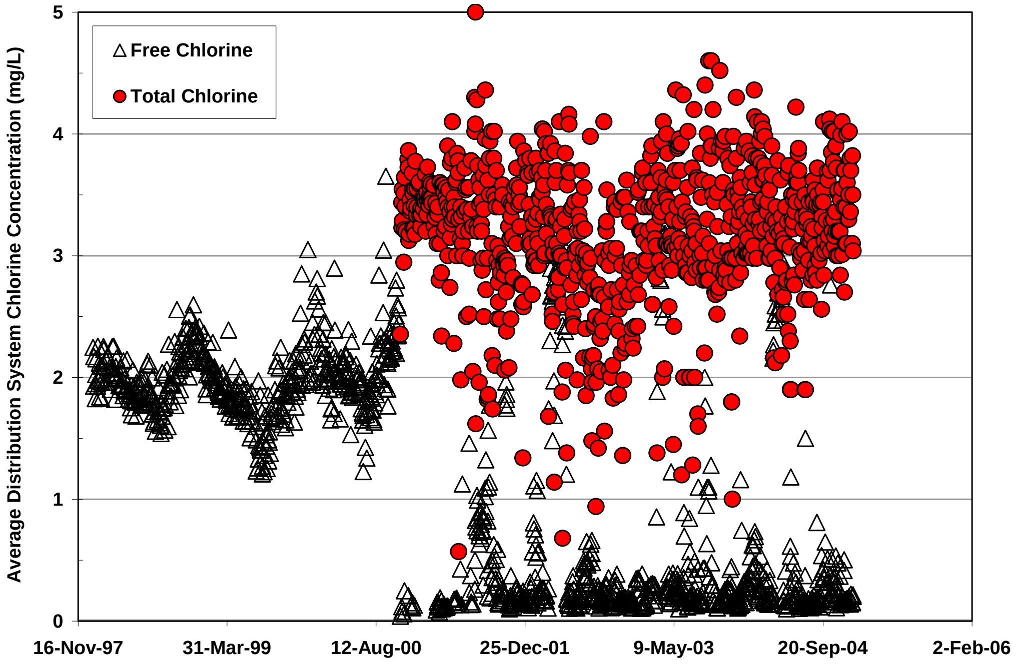


Figure 22. Average free and total chlorine concentrations for water samples collected from different sampling sites within the distribution system (1998 -2004)

Figure 23 shows a plot of average free chlorine residual levels during LCR compliance monitoring periods along with the 90th percentile lead data for the period January 1992 – December 2004. The 90th percentile lead levels were low (less than the LCR AL) during periods of high free chlorine residuals (July – Dec 1994 through July – Sept 1999) and high (greater than the LCR AL) during periods of low free chlorine residuals corresponding to disinfection with chloramines (July 2001 – June 2002 through July – Dec 2004). Statistical analyses were not performed due to limited data. However, the graph presents interesting information about a potential relationship between free chlorine residuals and lead release that could be explored as follow-on work.

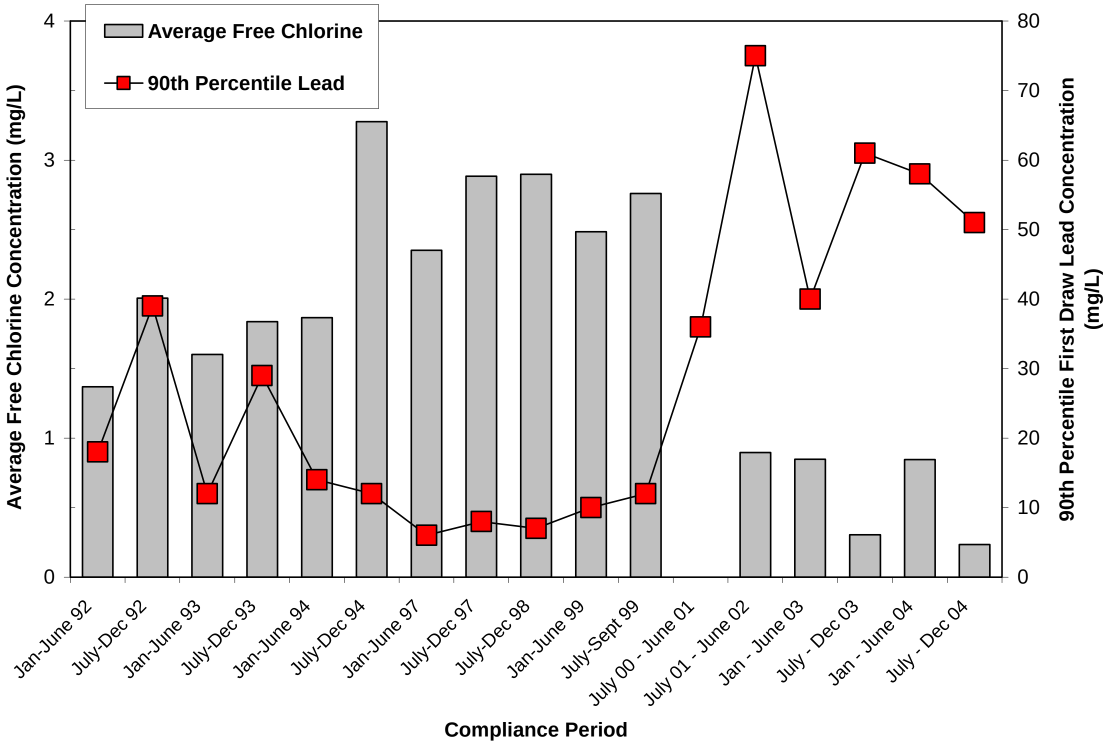


Figure 23. Average Free Chlorine Concentration (over the LCR compliance period) and 90th Percentile Lead vs. Time

5.5 Distribution System pH Levels and pH Variations

This section provides information about the following:

- pH variations and their effect on lead corrosion and solubility
- Spatial and seasonal pH variations
- The possible effect of lower operating pH per OCCT designation
- OCCT changes and their quantifiable impact on lead release

5.5.1 pH Variations

An evaluation of pH data collected at the entry points and within the DCWASA distribution system indicated that pH variations were observed seasonally as well as spatially from the entry points to sampling locations within the distribution system. pH has a significant influence on lead corrosion and solubility, especially for the typically observed Pb (II) species such as cerussite and hydrocerussite. Varying pH levels can significantly affect the formation of protective scales on the interior of the pipes and the capability of the system to maintain these scales in a stable form. In a recent study, Lytle and Schock (2005a) found that changes in pH could destabilize passivating films on pipe interiors, possibly resulting in increased lead solvency and release of scale particles. Several corrosion control studies prepared for DCWASA or WA recommended that distribution system pH should be maintained at a consistent level. For example, a study by ECG, Inc. (1994) concluded that WA water treatment plants should optimize current practices by rigorously maintaining a consistent pH level that would optimize the Langelier Saturation Index in the positive range, as close to zero as possible. An expert review of the ECG study (1994) by Jonathan Clement in 1996 recommended that maintenance of a consistent distribution system pH, regardless of treatment selection, should be addressed. Clement (1996) also recommended that pH variations of more than 0.5 pH units should be avoided. A study by CH2MHill (2004) evaluated two corrosion control options, both of which required a constant pH: (1) maintaining a constant, high pH at the two water treatment plants using either quicklime (current practice) and/or sodium hydroxide; and (2) feeding a corrosion inhibitor such as orthophosphate while maintaining a constant pH of about 7.7 throughout the year. A summary of these corrosion control study reports is provided in Appendix A.

Daily average pH at the entry points to the distribution system (Dalecarlia and McMillan Water Treatment Plants) and daily average pH in the distribution system are plotted as a function of time in Figure 24.

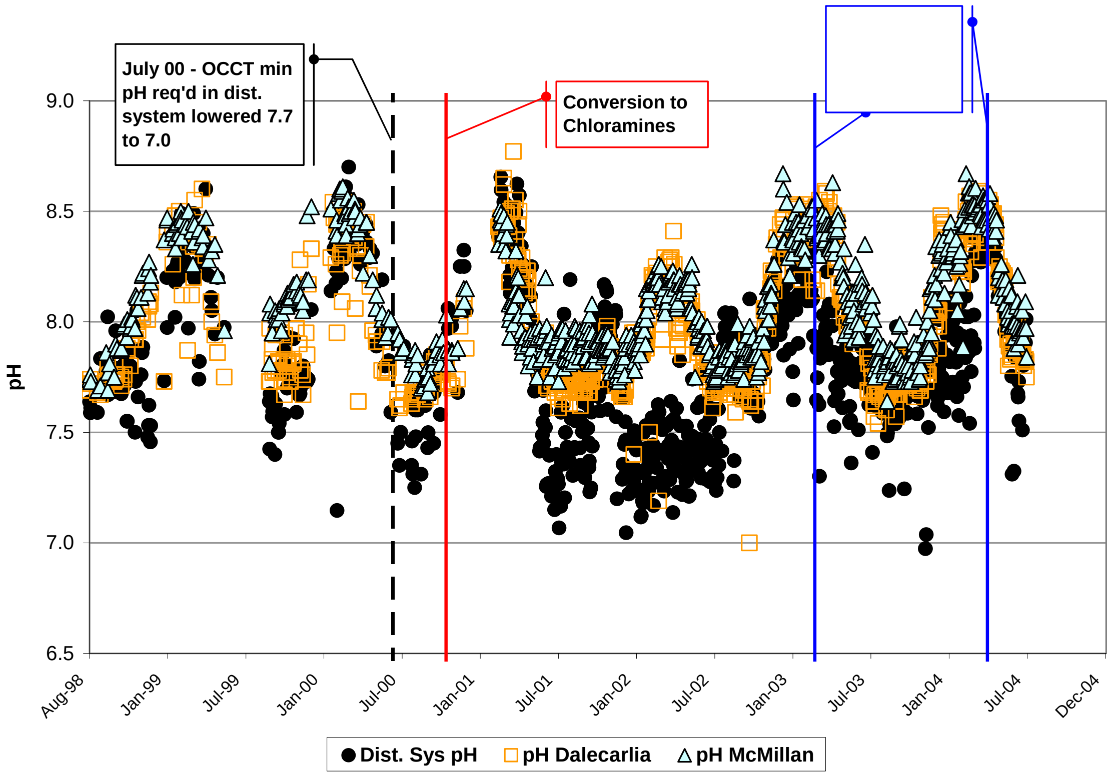


Figure 24. Average daily pH at the distribution system entry points (Dalecarlia and McMillan) and in the distribution system (1998 through 2004)

The differences in daily average pH for samples collected at the entry points compared to samples collected in the distribution system are plotted as a function of time in Figure 25. A positive difference as shown in Figure 25 is an indication that the daily average pH was lower in the distribution system compared to the entry point. A negative difference indicates that the pH in the distribution system was higher than the pH at one of the entry points. In some cases this observation was attributed to the difference in pH at both entry points, and thus the pH in the distribution system could have been intermediate between pH at Dalecarlia and McMillan entry points.

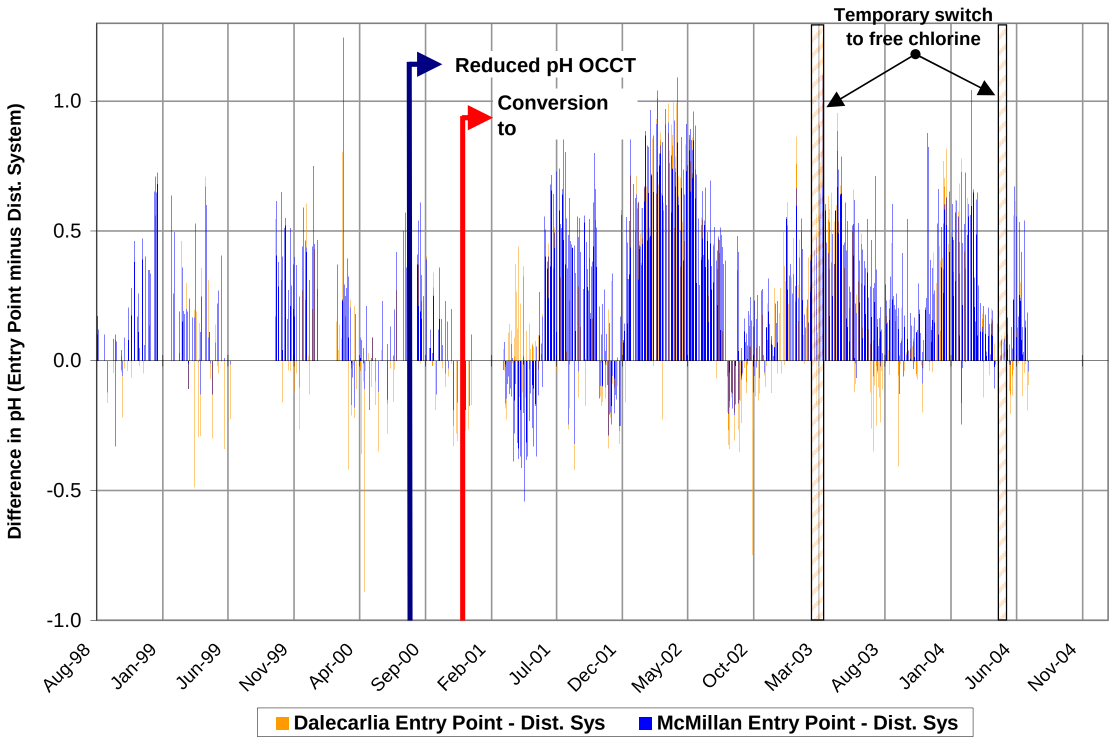


Figure 25. Difference between the average water pH at the distribution system entry points and the average pH of water collected at different sampling sites throughout the distribution system (1998 through 2004)

5.5.2 Spatial pH Variations

Data in Figure 24 and Figure 25 indicate that pH levels in the distribution system were frequently 0.5 pH units less than, and in some instances as much as 1 pH unit less than, the pH of finished water discharged from the water treatment plants. In Figure 25 the difference in pH is calculated by subtracting the average pH value in the distribution system from that at the respective distribution system entry points (Dalecarlia and McMillan). These data indicate pH differences greater than the recommended allowable pH difference based on studies by Clement (1996) and CH2MHILL (2004). As such, these spatial pH variations could have caused adverse impacts on the stability of lead scales and thus contributed to lead release.

5.5.3 Seasonal pH Variations

Figure 24 shows seasonal variation in pH, which was allowed to occur in the DCWASA distribution system as part of the modified OCCT. During 1998 and 1999, the seasonal trend in the average daily pH in the distribution system generally followed the seasonal trend exhibited by the finished water discharged at the water treatment plants.

5.5.4 Lower pH and Modified OCCT

Beginning with the reduced pH OCCT in 2000, the average daily pH in the distribution system appeared to be noticeably lower than the finished water at the treatment plants during 2000, 2001 and 2002. The cause of this change in pH between the point of entry and distribution system is unknown. During 2000 and previously, pipe scales presumably were acclimated to conditions of free chlorine and likely were dominated by Pb (IV) species. After the switch to chloramines in November 2000, the average daily pH in the distribution system generally remained low during 2001 and 2002. Under these new conditions, the pipe scales likely were disrupted by the change in ORP and chemical interactions likely were dominated by Pb (II) species. Further, low pH conditions presumably were not favorable for the formation of stable lead scales. As a consequence, low pH conditions, coupled with a reduction in ORP, likely contributed to elevated lead levels after the switch in disinfectant to chloramines.

While Pb (IV) compounds are thought to have lower solubility than Pb (II) species, solubility models also suggest that Pb (IV) solubility decreases with decreasing pH. As discussed in a Section 5.2, in Pb (II) and Pb (IV) solubility models, Schock et al. (2001) found that the PbO_2 solubility minimum could occur at around pH 4. This phenomena is opposite of the trend observed with Pb (II) where solubility was reduced with increasing pH (Schock and Giani, 2004). Based on this understanding, the lower pH range in the DCWASA system may have previously been adequate for maintaining Pb (IV) scales under high free chlorine conditions, but too low of a pH for maintaining Pb (II) scales under chloramine conditions.

5.5.5 Optimal Corrosion Control Treatment (OCCT)

The OCCT changes affecting pH control are discussed in detail in Section 2.4. This section provides more in-depth analyses of the OCCT changes in an effort to quantify their impact on lead release.

Distribution system pH varied from 7.0 to 8.9 over the years 1998 to 2004, and it appears to vary seasonally, peaking in March or April every year except for the year 2002 (Figure 3, Figure 9, and Figure 24). In late 2001 and early 2002, distribution system pH was significantly lower than in other years, with 3-month average pH values less than 7.5.

System-wide pH data were analyzed to determine if statistical differences in pH occurred before and after the observed increase in the 90th percentile lead levels for the DCWASA system. Figure 26 shows a plot of the average, range, and standard deviation of daily average pH data collected before and after the compliance period of July 2000 through June 2001. For each “box and whisker” diagram shown in the graph, the horizontal line in the center of the box represents the average, the symmetrical box represents the standard deviation, and the vertical bar represents the minimum and maximum average of daily pH data collected during the designated compliance period (x axis). The solid circles depict the 90th percentile lead levels (secondary y axis) for the designated compliance periods. The disinfectant conversion, which occurred on November 1, 2000, and the change in allowable minimum pH for OCCT, which occurred in February, 2000, are shown by the vertical lines annotated in Figure 26. Results indicate that the average pH before the disinfectant conversion ranged from 7.6 to 8.1 and it ranged from 7.4 to 7.9 after disinfectant conversion. Results also indicate that the standard deviation and ranges of pH data appear to be similar, with the exception of the narrow range of values measured during the July through December 1999 compliance period. While the pH range before and after the conversion is similar, the lowest pH values occurred after the conversion during the July 2001 – June 2002 LCR monitoring period. This period corresponds with the highest 90th percentile lead level as shown in Figure 26.

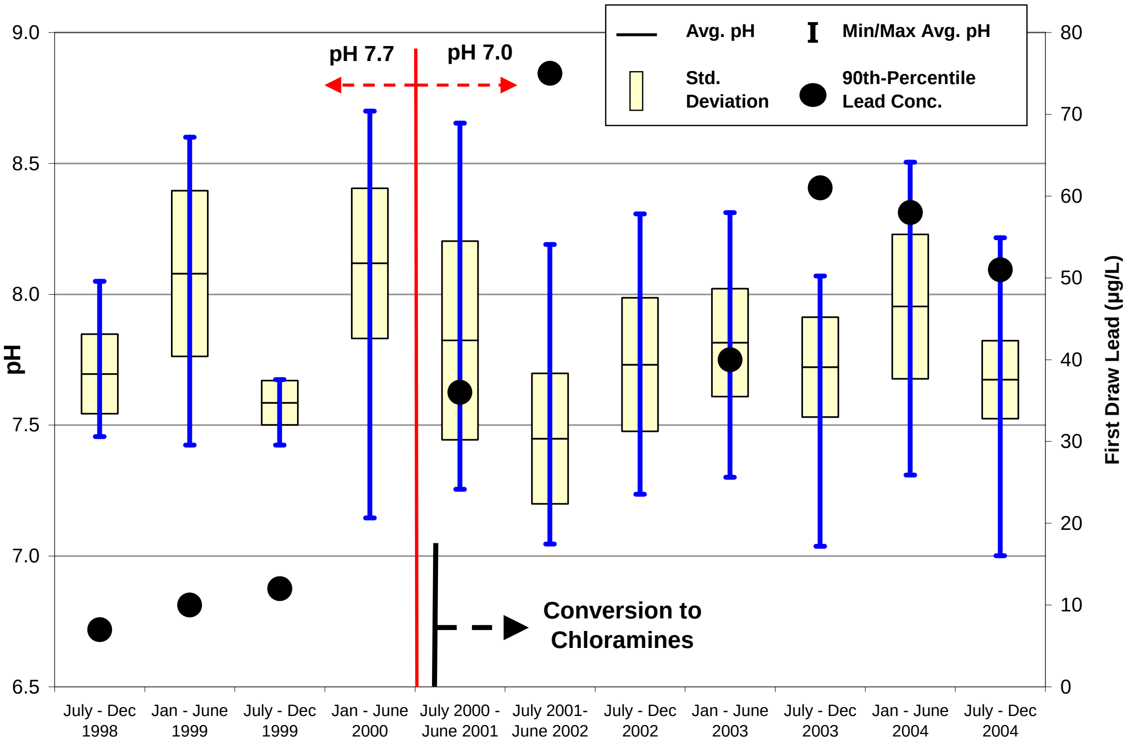


Figure 26. Average daily pH and lead concentrations in first draw water samples before and after the conversion from free chlorine to chloramines as the residual disinfectant

Lead data were evaluated as a function of pH before and after the pH changes in July 2000 as defined in the OCCT, and prior to orthophosphate addition. No correlation could be found between total first draw lead concentrations and the average daily distribution system pH values. The lack of a correlation between these two parameters was likely due to: (1) the variability of both lead levels and pH levels measured, and using an aggregate of pH and lead data collected at different locations throughout or connected to the distribution system; and (2) variations between lead sources and lead levels in individual LCR monitoring sites. The results did show that system-wide lead levels were greater after OCCT pH changes (most of the data also corresponds to the post-chloramines conversion period).

Table 13 summarizes the evaluation of data and information regarding distribution system pH variations.

Table 13. Summary evaluation of data and information – distribution system pH variations

Data and Information Considered	Evaluation of Data and Information Pertaining to this Possible Cause
Distribution system pH and alkalinity, 1998–2004 Distribution system entry points, pH and alkalinity, 1998–2004 (except for alkalinity data missing for 2000–2001) HDR/EES analysis of WA pH data for entry points to the distribution system 1992-2004 in conjunction with other historical events (OCCT and disinfection changes) HDR/EES analysis of DCWASA lead data for LCR compliance, 1998–2004 Correspondences pertaining to LCR compliance (USEPA and DCWASA, 1997–2004) Corrosion control studies (ECG, 1994; CH2MHill, 2004) Expert review (Clement, 1996) Schock and Giani (2004)	Data is plentiful, but confounding factors make interpretation difficult. The cause of lower distribution system pH levels compared to entry point pH levels following the disinfectant change is unclear. pH variations and lower pH likely play an important contributing role to scale disturbance and lead release, along with a disinfectant change.

5.6 Conversion from Elevated Free Chlorine to Chloramines for Final Disinfection

On November 1, 2000, WA converted from free chlorine to chloramines for final disinfection to reduce disinfection byproduct formation and to improve residual disinfection in the distribution system. This change from free chlorine to chloramines has been implicated as a potential causative factor in lead release, especially from lead service lines. This section provides discussion on lead compliance monitoring data and historical wastewater metals information collected before and after the conversion to chloramines. In addition, this section provides discussion on special sampling data collected during periods when WA switched to free chlorine for biofilm control (referred to as a temporary disinfectant change) and lead profiling data collected during the temporary disinfectant change. Further discussion is provided in this section with regard to recent advances in theoretical understanding of oxidation reduction potential and its impact on lead scales and the solubility of various forms of lead.

5.6.1 LCR Monitoring Results

To evaluate how lead levels changed before and after the conversion to chloramines, lead compliance monitoring data were evaluated both on a compliance period basis and on a monthly basis for the time period from July 1997 through October 2004. Figure 27 shows the LCR compliance data for this period, indicating when the minimum allowable pH at distribution system sites was lowered from 7.7 to 7.0, and when the conversion from free chlorine to chloramines occurred. The minimum allowable pH in the distribution system was lowered immediately prior to collection of compliance samples for the July 2000 to June 2001 compliance period. The conversion to chloramines occurred in November 2000 in the middle of this compliance monitoring period. A total of 53 valid compliance samples were collected during the July 2000 through June 2001 compliance period, with 40 samples collected from July through October 2000 when DCWASA was using free chlorine and 13 samples collected in June 2001 after the switch to chloramines. Although there are several high lead levels measured prior to the conversion (levels of 119 μg/L, 113 μg/L, and 128 μg/L), the percentage of samples with lead levels >15 μg/L was greater after the conversion to chloramines (46%) than before the conversion (8%).

Three elevated lead results occurred just prior the switch to chloramines. It is difficult to determine, but unlikely that these few results have any significance with respect to pH. A lead result occasionally reached this magnitude earlier under higher pH and high free chlorine residuals. Similarly an occasional elevated result occurs under current conditions with orthophosphate (Smith, 2007). It is possible that lead release and low lead levels had been maintained by the high oxidation-reduction potential of the water and not controlled by pH.

Figure 28 displays the average and 90th percentile lead levels by compliance period. The average and 90th percentile lead levels were higher after chloramination began, when compared to the seven previous compliance periods. Figure 29 again shows the LCR compliance data for the period from 1997 through 2004, with the overall average lead level before conversion to chloramines (when free chlorine was used from July 1997 through October 2000) of 5 µg/L, approximately one-fourth the average lead level measured after conversion to chloramines (November 2000 through July 2004), which was 22 µg/L. This difference is significant, with a p-level of 0.0000 (t-test statistics as reported using StatSoft® STATISTICA software, Release 5.1). The p-level represents the probability of error involved in accepting the hypothesis that there is a difference in the two means.

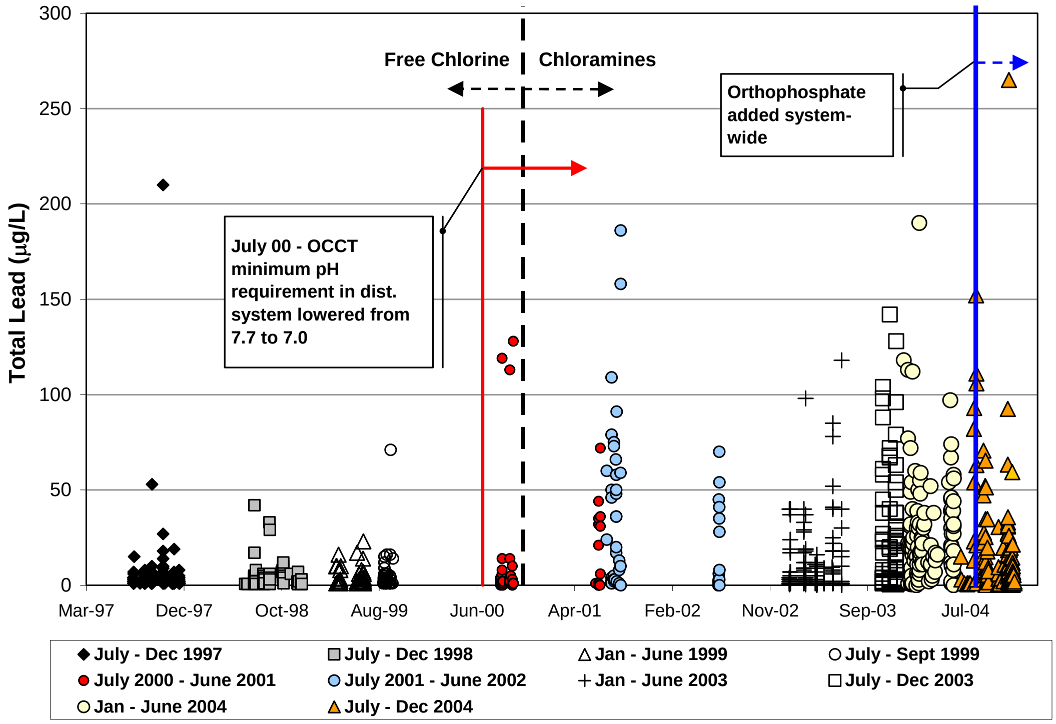


Figure 27. Lead concentrations in first draw water samples collected during different time intervals (July 1997 through December 2004)

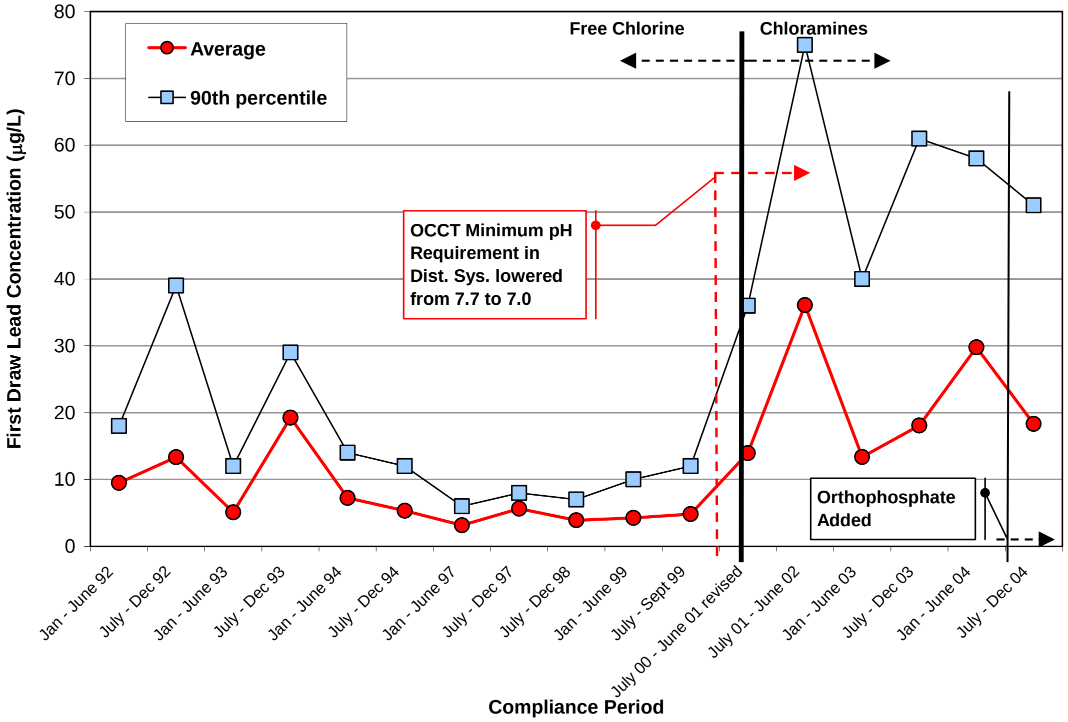


Figure 28. Average and 90th percentile lead concentrations in first draw water samples during different compliance periods (January 1992 through December 2004)

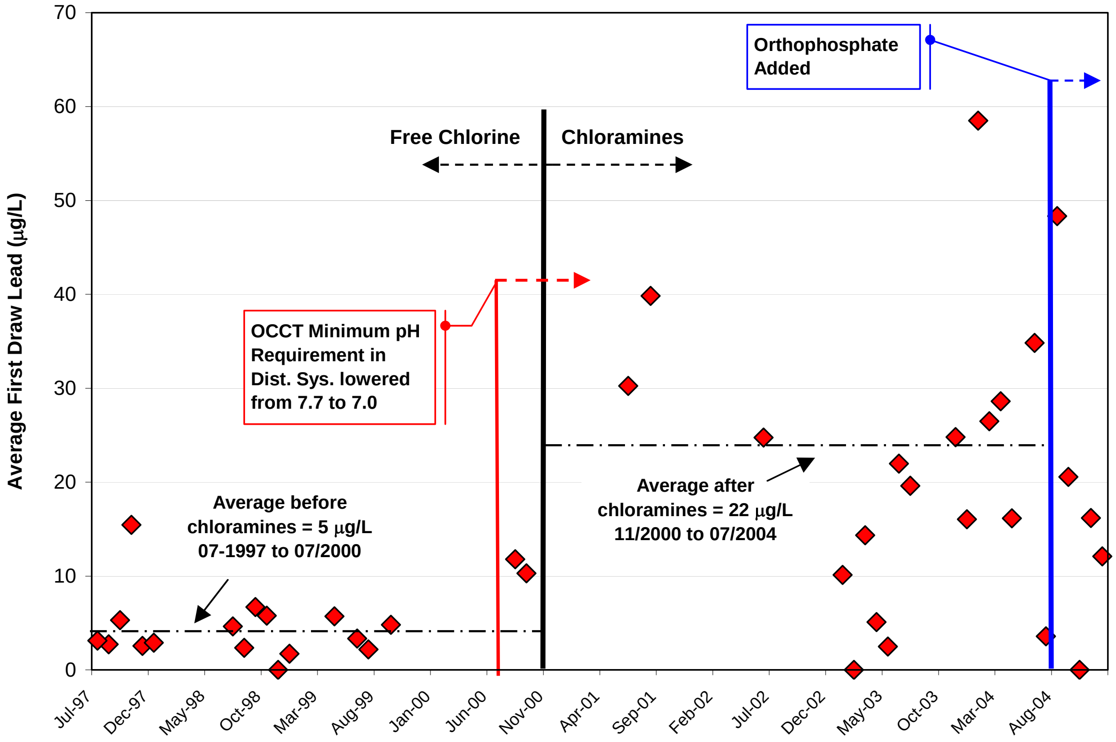


Figure 29. Average lead concentrations in first draw water samples collected during different months (July 1997 through October 2004)

5.6.2 Historical Data on Wastewater Metals

DCWASA examined historical data on lead, copper, and zinc loading to the Blue Plains Wastewater Treatment Facility before and after the November 1, 2000 conversion to chloramines to determine if the change increased metals loading. DCWASA found no significant increase in lead, copper, or zinc levels after November 2000 (Rizzo, 2004).

5.6.3 Lead Levels during Temporary Disinfectant Change

Chloraminated systems may periodically switch to free chlorine for the purpose of controlling microbial regrowth in the distribution system. This section discusses the temporary switch to an alternate disinfectant (free chlorine) for both 2003 and 2004.

USEPA Region 3 compared LCR lead results during 2003 during a temporary switch to free chlorine to periods when chloramine was used for disinfection. Table 14 presents the LCR sampling results for the first half of 2003 when free chlorine was used from March 10 to April 10, 2003. Sampling results show that after chloramine addition was resumed in April, the number of samples with elevated lead levels increased. Another potential contributing factor to the higher number of samples with elevated lead levels in late spring may have been higher water temperature; however, it is difficult to evaluate the relative impact of water temperature versus the change in disinfectant practices on changes in lead levels measured at the tap.

Table 14. LCR lead results for January through June 2003

LCR Sampling Results			
	Before March 10, 2003 (chloramines)*	**March 10–April 10, 2003 (free chlorine)****	**From April 11 (chloramines)*****
Number of samples	22	29	53
Range of First Draw Lead (µg/L)	ND to 62	ND to 21	ND to 118
Average First Draw Lead (µg/L)	7	5	13
Number of Samples >15 µg/L	3	2	12
% of Samples > 15 µg/L	14	7	23

ND = Not Detected. *Source: USEPA Region 3*

**LCR samples January 1 through January 31, 2003*

***LCR samples March 13 through March 28, 2003*

****LCR samples April 17 through June 30, 2003*

USEPA Region 3 also presented lead results in samples collected at 12 specific sampling sites during the March through April 2003 free chlorine period and samples collected at these same sites during the July 1, 2001 to June 30, 2002 monitoring period when chloramine was being used. Of these 12 sites, 8 had lead levels greater than 15 µg/L during the 2001 through 2002 monitoring period (chloramine period), whereas only 5 sites had elevated lead levels during the March 2003 monitoring period (free chlorine period). While not a rigorous statistical evaluation, these results suggest that elevated lead levels occurred during use of chloramines.

HDR/EES summarized LCR lead results for the period in 2004 when free chlorine or chloramines were used. These results are presented in Table 15. These data indicate that higher lead levels were apparently measured during chloramination compared with lead levels measured during the period of free chlorine use. It is worth noting that some of the data in Table 15, after the temporary disinfectant change to free chlorine, includes the period after June 1, 2004 when orthophosphate had been introduced into the 4th High Pressure Zone, which was almost 3 months earlier than orthophosphate addition to the entire DCWASA system (Appendix A – Timeline). Based on available location data from LCR monitoring and maps of the 4th High Pressure Zone, some sampling sites included in the analysis shown in Table 15 may be in the 4th High Pressure Zone. This scenario could cause additional variability because some results may be affected by orthophosphate. Further spatial analyses may be beneficial to more clearly define conditions under which samples were taken, and potential impact on lead results.

Table 15. LCR lead results for March through June 2004

	Before April 2, 2004 (chloramines)*	April 2, 2004 to May 7, 2004 (temporary disinfectant change to free chlorine)**	From May 8, 2004 (chloramines)**
Number of samples	28	12	30
Range of First Draw Lead (µg/L)	2 – 190	3 – 38	1 – 97
Average First Draw Lead (µg/L)	28	17	37
# Samples >15 µg /L	19	4	23
% of Samples >15 µg /L	68%	33%	77%

**LCR samples March1, 2004 through April 1, 2004*
***LCR samples April 7, 2004 through April 29, 2004*
****LCR samples June 2, 2004-June 17, 2004.*

5.6.4 Lead Profiling during Temporary Disinfectant Change

Limited LCR data for lead were available during the temporary disinfectant change. Consequently, HDR/EES also reviewed an additional source of data – lead profiles – taken during chloramine disinfection and during a temporary change to free chlorine disinfection.

Lead profile data collected during periods of chloramination was compared to periods of free chlorine use during the 2004 temporary switch to free chlorine. Fourteen profiles were completed during the period when chloramines were used (December 2003 through March 2004); 12 profiles were completed during the temporary switch to free chlorine that occurred from April 1, 2004 through May 7, 2004; 2 sites were completed after the temporary switch to free chlorine when chloramines were re-introduced to the system (May 8, 2004 through July 16, 2004); and 17 profiles were completed after orthophosphate addition (December 2004 through January 2006). Appendix A contains graphical summaries of these 45 lead profiles grouped by the period in which they were collected (i.e., during chloramination, during the temporary switch to free chlorine, after the temporary switch to free chlorine when chloramination was resumed, and during post-orthophosphate addition). Review of these data indicates that higher lead levels were experienced during the period when chloramination was implemented when compared with periods when free chlorine was used temporarily.

Lead profile data were collected at five specific sites during periods of chloramination and periods of the temporary switch to free chlorine, providing data with which to compare the impact of disinfection change on lead levels at specific sites. These data are displayed in Figure 30 through Figure 34. Each profile is annotated to indicate which samples were representative of standing water in the premise plumbing, the lead service line, or the water main. This information regarding the segment of the piping system was based on notes included with the sampling results. Results from four of the five sites indicate that lead levels were lower during periods of free chlorine compared with lead levels measured when chloramines were used for disinfection. At House #1 (Figure 30), total lead levels representative of the lead service line reached 80 µg/L when chloramines were used, but were less than 10 µg/L during the temporary switch to free chlorine. House #2 (Figure 31) shows profiles after a partial lead service line replacement, during both chloramination and during the temporary switch to free chlorine. There appears to be a small increase in lead levels in the LSL segment during the temporary switch to free chlorine, possibly due to scale disturbance. However, the lead levels measured during both periods were relatively low, making it difficult to distinguish differences that may have been due to the disinfectant conversion. In addition, the date for the background sample (sample “0”) and the first liter sample indicate anomalous results with dissolved lead higher than total lead. The reason for this anomaly is unknown but could also be attributed to analytical inconsistencies at these low lead levels.

At House #3 (Figure 32), total lead levels reach 24 µg/L in the LSL segment during chloramination. During the temporary switch to free chlorine, the first 1-liter sample exhibited high total lead (110 µg/L) primarily due to particulate lead. The remaining samples were less than 10 µg/L during the temporary switch to free chlorine. The high particulate lead for House #3 at sample ‘X’ could be attributed to scale disturbance and detachment of particulate lead, since ‘X’ represents water hammer conditions, as discussed previously. At House #4 (Figure 33), the highest total lead levels measured were 110 µg/L during chloramination and only reached 9.7 µg/L during the temporary switch to free chlorine. Total lead levels at House #5 (Figure 34) reached 82 µg/L during chloramination and 45.6 µg/L during the temporary switch to free chlorine. These results, as summarized in Table 16, therefore indicate lower lead levels during the temporary switch to free chlorine than during chloramination. Additional details regarding special conditions (such as partial LSL replacements) under which the profiles were conducted are listed in Appendix A. Table 17 summarizes the evaluation of data and information regarding conversion from free chlorine to chloramines for final disinfection.

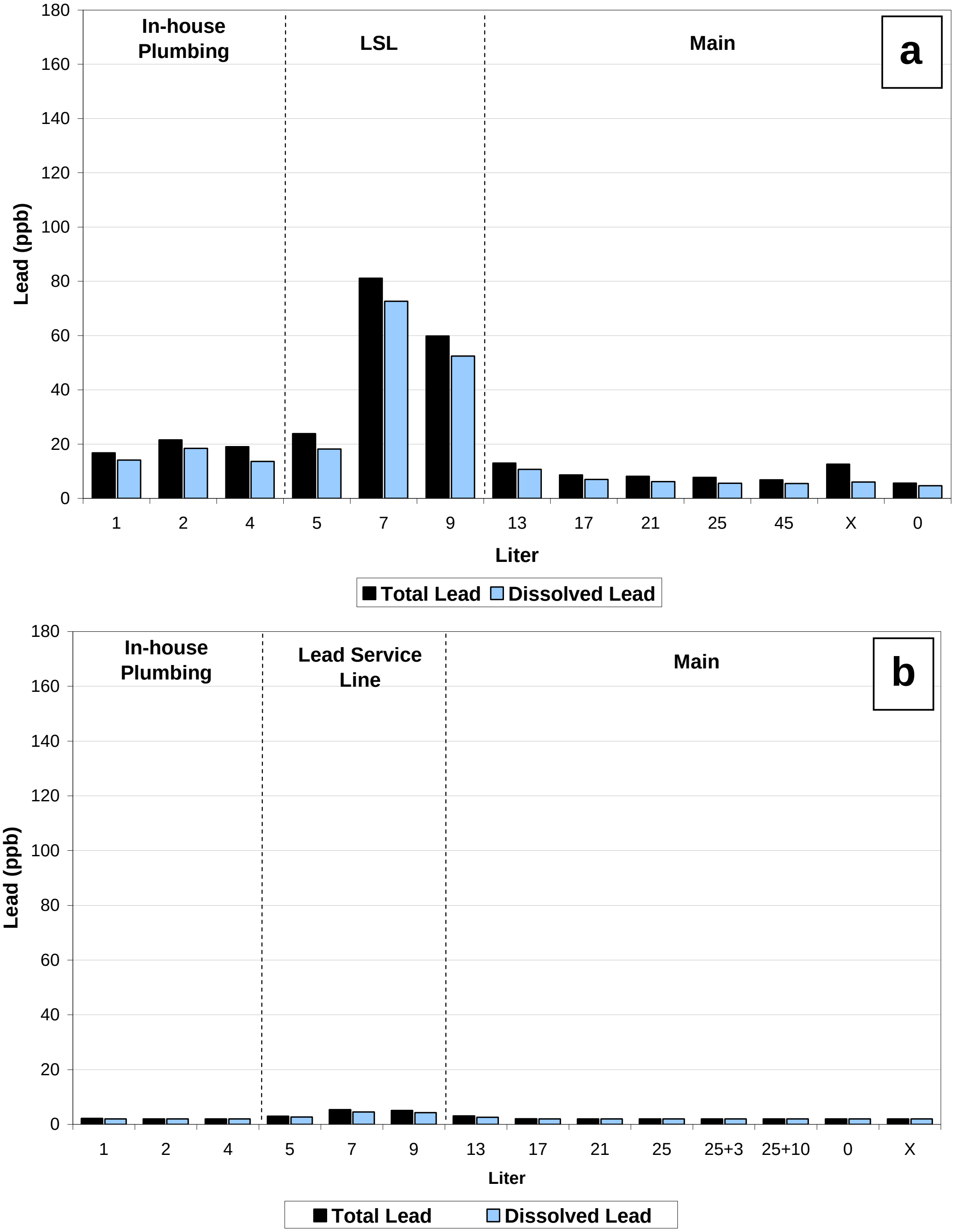


Figure 30. Lead profiles for House #1 when a) chloramines were being used as the disinfectant (sample collected January 13, 2004) and b) during a temporary switch to free chlorine as the disinfectant (sample collected April 29, 2004).

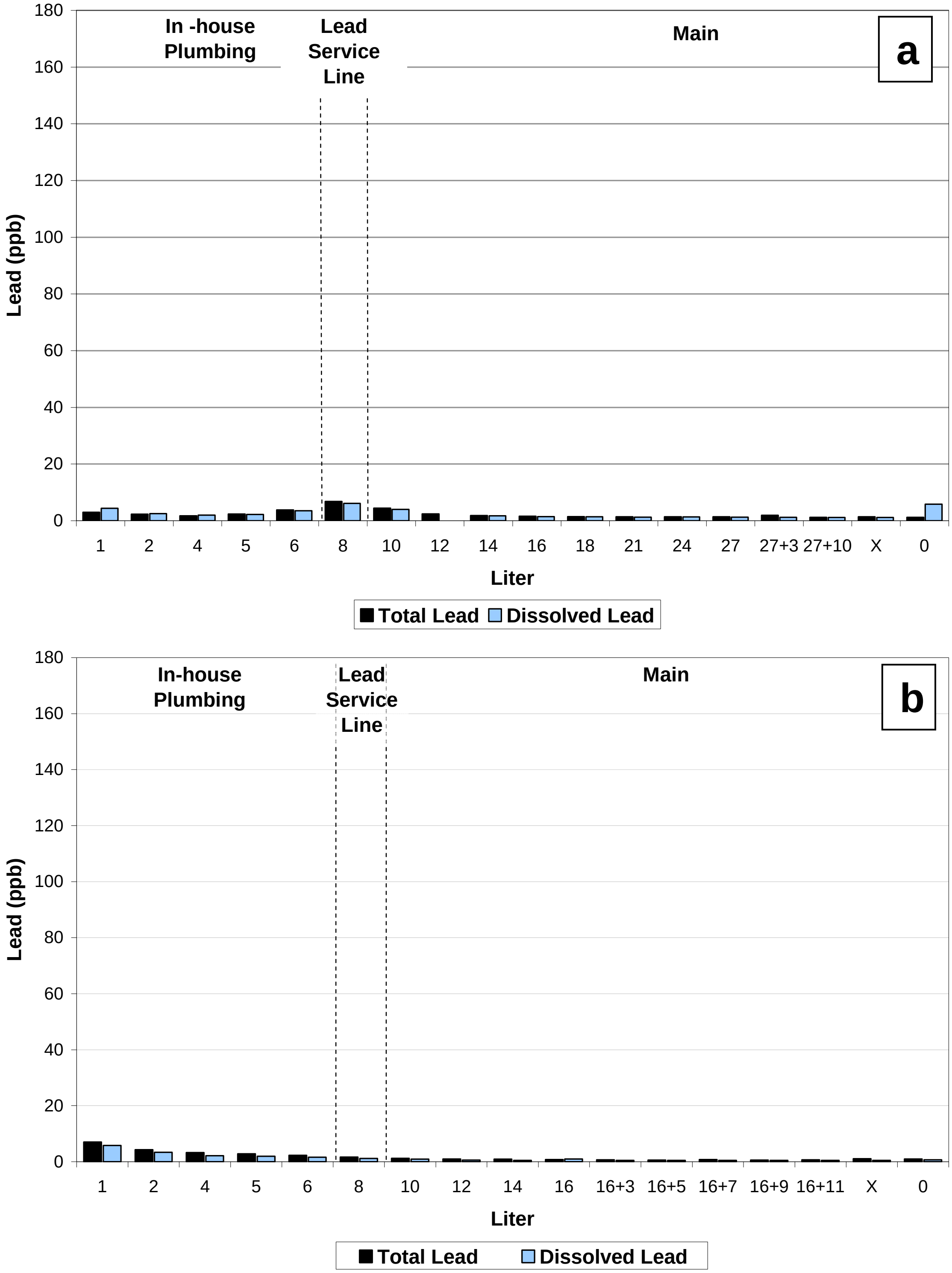


Figure 31. Lead profiles for House #2 when a) chloramines were being used as the disinfectant (sample collected February 24, 2004) and b) during a temporary switch to free chlorine as the disinfectant (sample collected April 26, 2004).

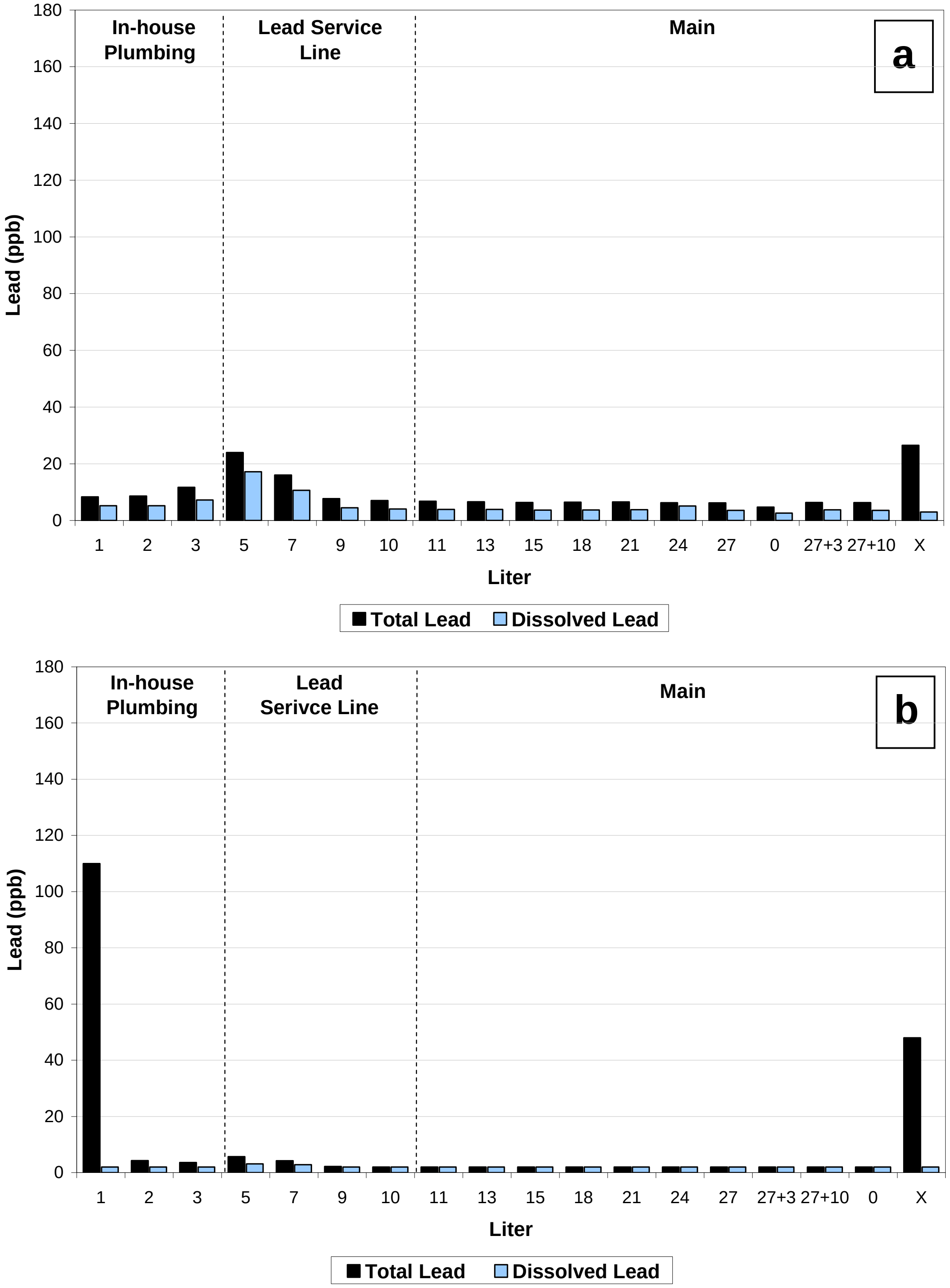
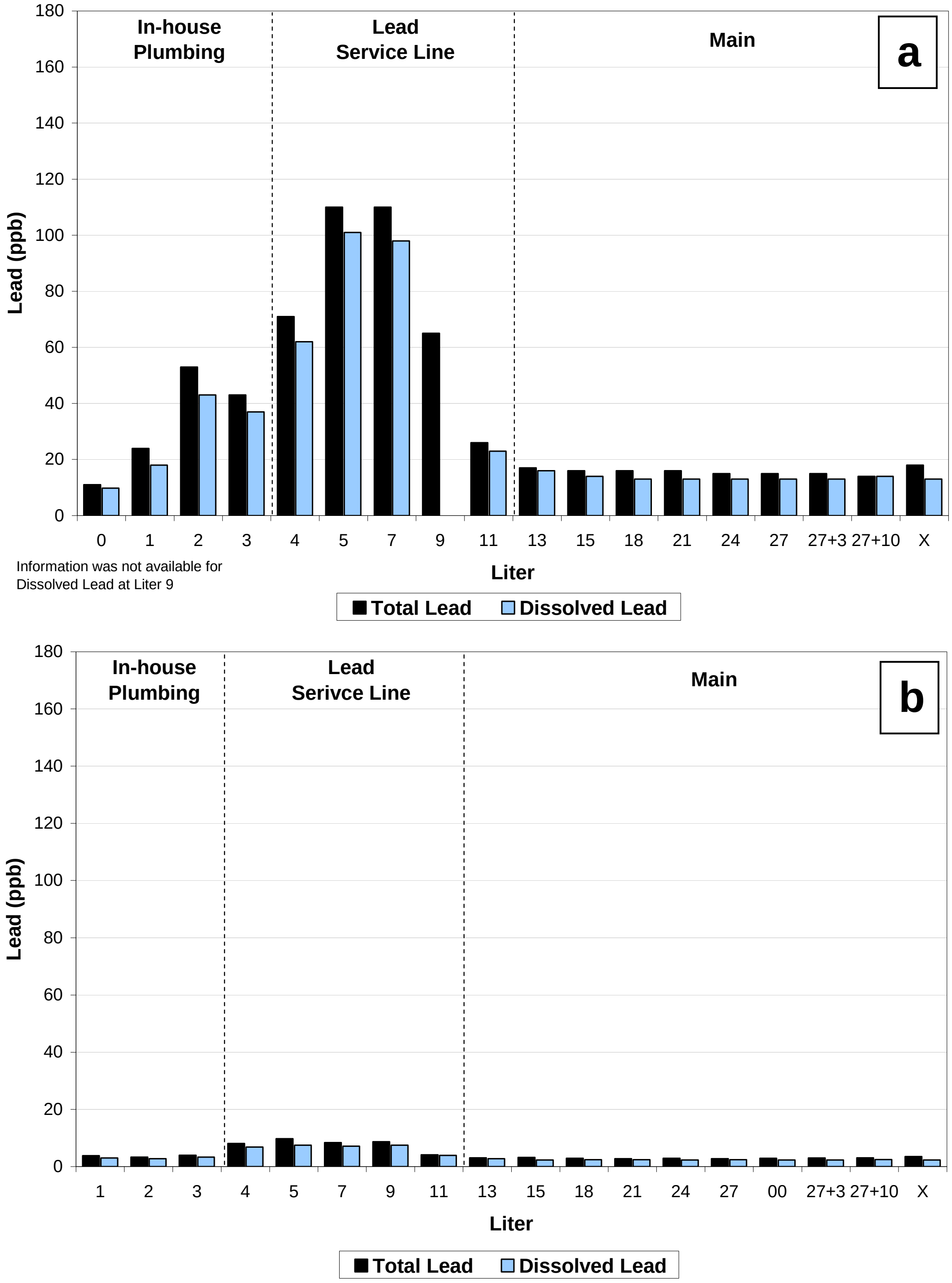


Figure 32. Lead profiles for House #3 when a) chloramines were being used as the disinfectant (sample collected March 30, 2004) and b) during a temporary switch to free chlorine as the disinfectant (sample collected April 30, 2004).



Information was not available for
Dissolved Lead at Liter 9

Figure 33. Lead profiles for House #4 when a) chloramines were being used as the disinfectant (sample collected March 31, 2004) and b) during a temporary switch to free chlorine as the disinfectant (sample collected May 7, 2004).

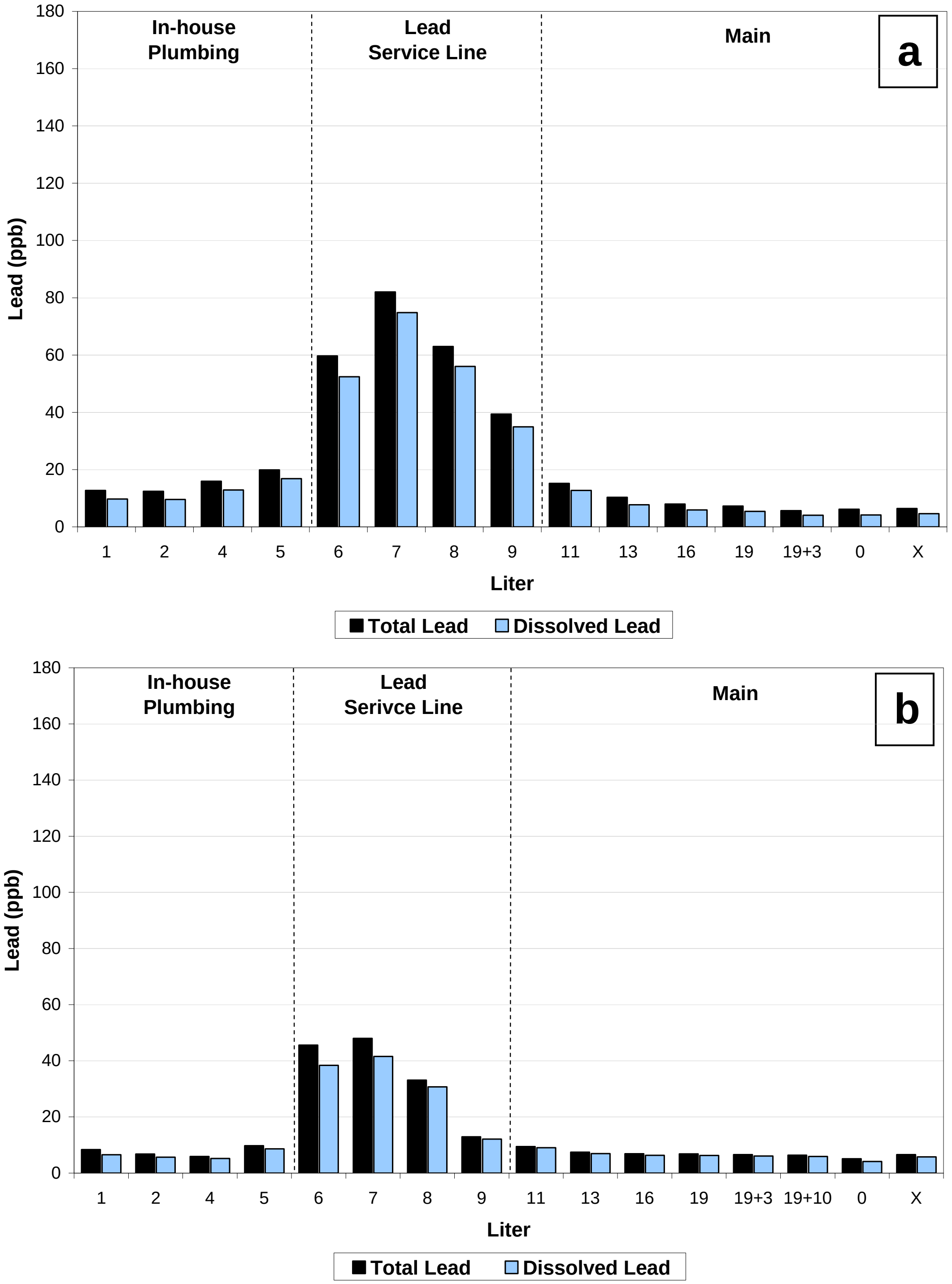


Figure 34. Lead profiles for House #5 when a) chloramines were being used as the disinfectant (sample collected February 9, 2004) and b) during a temporary switch to free chlorine as the disinfectant (sample collected May 18, 2004).

Table 16. Maximum lead levels measured from profiles during chloramination and periods of temporary disinfectant change to free chlorine

House	Maximum Lead Level Measured During Profile	
	Chloramination	Temporary disinfectant change to free chlorine
1	81	5.4
2	7	7
3	24	5.7*
4	110	9.7
5	82	45.6

**First draw contained high particulate lead; next highest sample was 5.7 μg/L lead.*

Table 17. Summary evaluation of data and information – conversion from free chlorine to chloramines for final disinfection

Data and Information Considered	Evaluation of Data and Information Pertaining to this Possible Cause
DCWASA lead monitoring data, 1994–2004. USEPA Region 3 analysis of LCR lead results for free chlorine periods vs. chloramines periods, 2002–2003. HDR/EES analysis of LCR lead results for free chlorine periods vs. chloramines periods, 2004. HDR/EES analysis of DCWASA Lead Profiles in Excel spreadsheet obtained from USEPA Region 3.	Higher lead levels were measured and the number of samples with elevated lead levels increased when chloramines were used, when compared to periods when free chlorine was used as a disinfectant.
HDR/EES analysis of DCWASA 4th High Pressure Zone hydrant WQP monitoring data (specifically ORP) in the timeframe leading up to, during and after the 2004 free temporary disinfectant change	Higher lead levels in LCR monitoring and lead profiles correspond to the periods of lower ORP typically observed during disinfection with chloramines. Lead levels in LCR monitoring and lead profiles appear to be lower during a period of higher ORP corresponding to the 2004 free temporary disinfectant change.
Laboratory and field studies as reported by Schock, Lytle, and Giani (see references) on mechanism and presence of Pb (IV) versus Pb (II) compounds on the interior of lead service pipes.	Occurrence of Pb (IV) compounds on DCWASA lead service line specimens supports the theory of formation of Pb (IV) compounds under higher ORP conditions.
USEPA Region 3 report on loadings to Wastewater Treatment Plant (WWTP) 2004 (report by G. Rizzo, USEPA Region 3, Spring 2004).	No significant difference in lead, copper, and zinc loading to the Blue Plains Wastewater Treatment Facility after the conversion to chloramines.

5.7 Distribution System Water Quality Characteristics

Water quality characteristics such as alkalinity, specific conductance, temperature, and organic levels and speciation can impact pipe scale formation and lead release in water distribution systems. Furthermore, the occurrence of biological events like nitrification also can potentially affect lead release in lead service line and premise piping. This section provides an evaluation of available water quality data regarding these characteristics in relation to lead levels in DCWASA tap water samples.

5.7.1 Alkalinity

System-wide alkalinity data were analyzed to determine if any statistical differences occurred before and after the pH adjustment for OCCT or following the disinfectant conversion. As shown in Figure 35, the average alkalinity in tap water samples ranged from 64 to 112 mg/L as $CaCO_3$ before the pH adjustment for OCCT and the disinfectant conversion. The average alkalinity ranged from 57 to 89 mg/L as $CaCO_3$ after the OCCT pH adjustment and disinfectant conversion. The range and standard deviation values also appear to be similar, except for the period when conversion occurred (2000-2001) and in the following compliance period (2001-2002). Both of these periods cover an entire year rather than 6 months, which could explain the higher variability in these results. These results generally indicate that the variation in alkalinity did not appear to be a primary contributor to the observed increase in lead following the conversion to chloramination. This is based on the fact that elevated lead levels persisted during both higher and lower alkalinity concentrations. A linear regression analysis between total lead concentrations and alkalinity in the distribution system before and after the OCCT pH change (not shown here) further indicated that there was no correlation between the two parameters.

5.7.2 Temperature and Specific Conductance

Temperature and specific conductance were also evaluated with regards to their variability before, during, and after the July 2000 – June 2001 LCR monitoring period (data not shown). For both parameters, there was no observed difference in their variability, and no correlation with lead levels, over these time periods. Nevertheless, previous findings indicate that either of these parameters, acting in concert with other parameters or by themselves, may influence corrosion rates.

Water temperature can affect lead corrosion rates (Schock et al., 1996); however, the impact of fluctuations in water temperature on corrosion rates is not straightforward. This is because temperature affects many other processes and parameters such as buffering capacity, lead solubility, dissolved inorganic carbon solubility, and processes like dissolution, diffusion, and precipitation. Schock et al., (1996) indicated that the response of passivated pipes to temperature variation will depend on the solubility trends of the non-lead solids which comprise the scale.

Specific conductance or conductivity is a function of the concentration and composition of dissolved solids in a water sample. Ions of particular interest in drinking water systems include sodium, calcium, magnesium, chloride, carbonate, and sulfate (AWWA, 2005). Increased conductivity values are indicative of higher concentrations of these and other ions. Greater conductivity means that the water is better able to complete the electrochemical circuit and conduct a corrosive current (AWWA, 2005). If sulfate and chloride are present at sufficient concentrations the water is likely to exhibit increased corrosiveness towards iron-based materials, depending on the mass ratio of chloride to sulfate. If the conductivity is composed primarily of bicarbonate and hardness ions, the water may be highly corrosive towards copper (Schock, 1999). Waters with low conductivity may also be corrosive to lead and increase lead solubility, since these waters tend to dissolve (corrode) materials with which they are in contact in an attempt to reach equilibrium (AWWA, 2005).

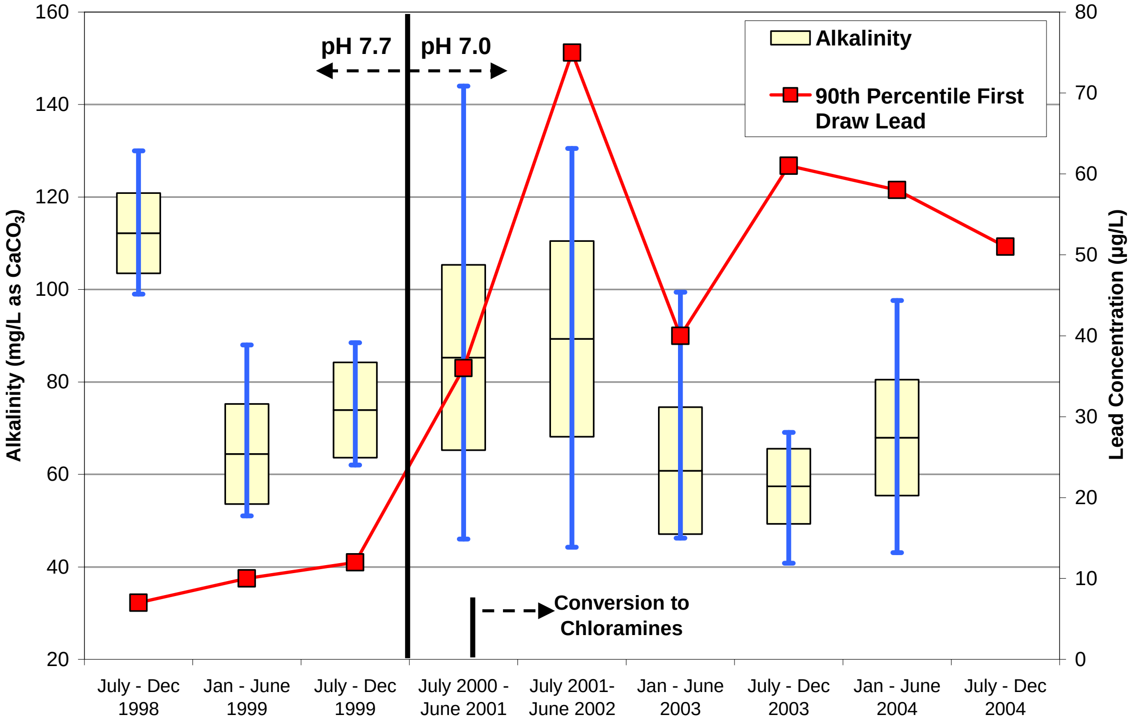


Figure 35. Average daily alkalinity and lead concentration in first draw water samples before and after the conversion from free chlorine to chloramines as the residual disinfectant

5.7.3 Natural Organic Matter

Previous research has suggested that natural organic matter (NOM) can influence corrosion processes (Colling et al., 1987, Marani et al., 1995, Schock et al., 1996; Hopwood et al., 2002; Korshin et al., 2005). The impact of NOM on corrosion processes depends on its concentration and physicochemical characteristics (Korshin et al., 2005). The characteristics of NOM may become altered by drinking water treatment processes, subsequently changing its impact on corrosion rates in distribution systems (Korshin et al., 2005). Korshin et al., (2005) found that NOM increased the soluble levels of lead and tin significantly. Here, the presence of NOM in suspension caused larger colloidal lead and solder particles to break down into smaller formations or contribute to soluble metal. Additionally, amorphous films were observed to form on corroding lead surfaces in the presence of NOM, though it was not noted whether this film acted as a passivating layer. Nevertheless, it was concluded that the concentration and characteristics of NOM present, in addition to pH and alkalinity, may be one of the important factors in establishing the predominance of and transitions between alternative lead solids during corrosion.

5.7.4 Nitrification

The occurrence of nitrification events in the DCWASA distribution system was investigated for potential impacts on water quality. While nitrification does not directly influence corrosion, it could potentially affect distribution system pH and alkalinity. The Washington Aqueduct has been sampling for nitrification indicator parameters (e.g., nitrite, nitrate, ammonia, pH, and bacteria), but no evidence suggesting that widespread nitrification was occurring in the distribution system was found (Rizzo, 2004). Furthermore, the occurrence of nitrification in the distribution system has not been documented by either DCWASA or USEPA Region 3 (Rizzo, 2005b). Although a more rigorous analysis of water quality data may reveal more information on the occurrence and subsequent impacts of nitrification in the DCWASA distribution system, based on the findings to date, it does not appear to be a significant factor.

5.8 Galvanic Corrosion of Lead Service Lines

One issue of concern associated with partial replacement of lead service lines with copper piping is the potential for galvanic corrosion. Galvanic couplings can create loss of metal at the anode and subsequent release into the water column. Theoretically, this mechanism could have a significant impact on lead corrosion rates when copper and lead are coupled. However, there is some uncertainty regarding the duration of accelerated corrosion rates caused by the coupling and whether an accelerated corrosion rate would be observed when the surface of the lead piping has been passivated. Partial LSLR was conducted during a timeframe when DCWASA continued to fail to meet the LCR 90th percentile AL. Therefore, the potential impact of this process on lead levels in service lines was evaluated further.

Reiber and Dufresne (2005) conducted a laboratory study to characterize the electrical impacts associated with galvanically-coupled lead and copper service lines to determine if replacing a portion of a lead pipe with copper piping might cause accelerated lead release in drinking water. This study was conducted using lead service lines which had been recently removed from DCWASA residences and water which had a baseline chemistry comparable to DCWASA's, including similar pH, alkalinity, hardness, and conductivity. The study was conducted under controlled laboratory conditions designed to accelerate lead release.

Reiber and Dufresne (2005) used two experimental set-ups for this evaluation: indirectly coupled cells and directly coupled pipe segments. Polarization cells connected in a hydraulic series with electrical connections between individual cells were used for evaluating indirectly connected lead and copper pipe segments. This approach allowed the researchers to manipulate cathode and anode ratios, the current flow between cells, and evaluate metal release. In the second experimental approach, ¾-inch diameter copper tubing was directly connected to each lead service line section. To ensure electrical coupling, the lead service line was grooved to match the end of the copper segment. In both experimental approaches, electrodes were used to measure changes in the pipe surface potential. The electrodes could measure potential shifts of a millivolt or less, while the theoretical impact of galvanic corrosion was expected to be on the order of hundreds of millivolts.

For the indirectly coupled experimental approach, the researchers found that the galvanic impact could be measured immediately for passivated lead service lines; however, the change in the pipe surface potential was on the order of only a few millivolts. A much greater shift in surface potential was measured when unpassivated lead service lines were indirectly coupled to copper piping.

When the pipes were directly connected, there was no significant impact on the pipe surface corrosion potential for the passivated lead service lines. However, the unpassivated lead piping did experience an electrochemical impact when directly coupled to the copper piping. Figure 36 presents a profile illustrating the surface potential along the length of directly coupled lead (passivated and unpassivated conditions) and copper service lines. Sample locations are represented by the electrode sites. The surface potential of the passivated lead service line deviates only slightly from the freely corroding lead surface potential, and only for the section of pipe that is within approximately 4 centimeters of the direct coupling.

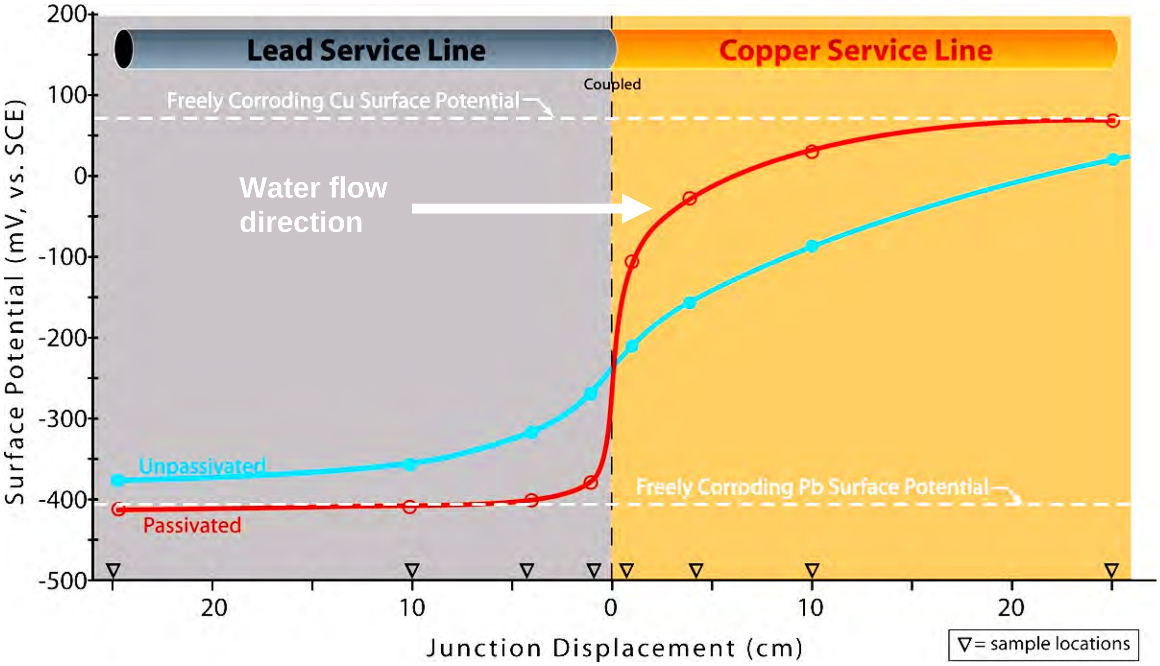


Figure 36. Surface potential along the length of directly coupled lead and copper service lines

This study also showed that the chlorine residual (free or combined) elevated the galvanic effect on the lead-copper couple by accelerating the galvanic influence on the copper service line, but the overall impact was nearly imperceptible on the lead service line. According to the investigators, conductivity had a greater effect on the galvanic process than chlorine residual.

It was also determined that for well-aged, passivated DCWASA lead service line specimens, the area of galvanic influence was limited when coupled to a new length of copper tubing, as in a partial lead service line replacement. Therefore, galvanic corrosion was likely not a major contributing factor to elevated lead levels initially or during continued failure to meet the LCR 90th percentile AL. A summary of the galvanic corrosion data from Reiber and Dufresne (2005) is given in Table 18.

Table 18. Summary evaluation of data and information – galvanic corrosion of lead service lines

Data and Information Considered	Evaluation of Data and Information Pertaining to this Possible Cause
Reiber and Dufresne (2005)	Laboratory testing results indicate that galvanic coupling of lead and copper service lines (e.g., partial lead pipe replacements) likely contributed minimally to lead release in drinking water in connections to the DCWASA distribution system.

5.9 Effect of Grounding Currents on Lead-Bearing Components

The impact of grounding currents on metal release from piping systems has been studied with the primary focus on copper tubing (Reiber and Dufresne, 2005). With respect to lead service lines, studies have produced conflicting results (Bell, 1998 and AwwaRF, 1996) regarding whether grounding currents present at the external pipe surface impact metal release from the internal pipe surface to drinking water.
Reiber and Dufresne (2005) conducted a laboratory study to investigate whether grounding currents could have a significant and prolonged impact on metals release from lead service lines and leaded-brass appurtenances. This study utilized a flow-through recirculation loop consisting of DCWASA lead service line segments, new copper tubing, water reservoir, and flow control and pumping hardware. High impedance reference electrodes were sited along the lead service line segments to monitor surface potential on the interior of the pipe while different current forms, amperages, voltages and grounding scenarios were applied to the test rig. Testing did not intend to replicate distribution system conditions, but instead to evaluate various scenarios by generating the highest possible metal release and the greatest lead service line surface effects.

Results showed that impressed currents (AC or DC) on lead service lines and copper service lines, including grounding type currents, had no impact on the internal corrosion of the household service lines or any other plumbing appurtenances that were tested. Figure 37 presents profiles of the surface potential response to AC and DC currents. The investigators concluded that there is likely no acceleration of corrosion associated with the conventional practice of electrical system grounding to household water systems. Reiber and Dufresne (2005) indicate that this may be the case because imposing an external current on the pipeline changes the potential of all surfaces, both external and internal, and everything in contact with the piping. The internal surface potential relative to the water contained in the pipe may not change since the potential of the water has been shifted to an amount equal to the shift of the potential of the interior pipe surface. Corrosion would occur when the internal surface potential changes relative to the water in the pipe. Table 19 shows the summary evaluation of data and information related to grounding currents.

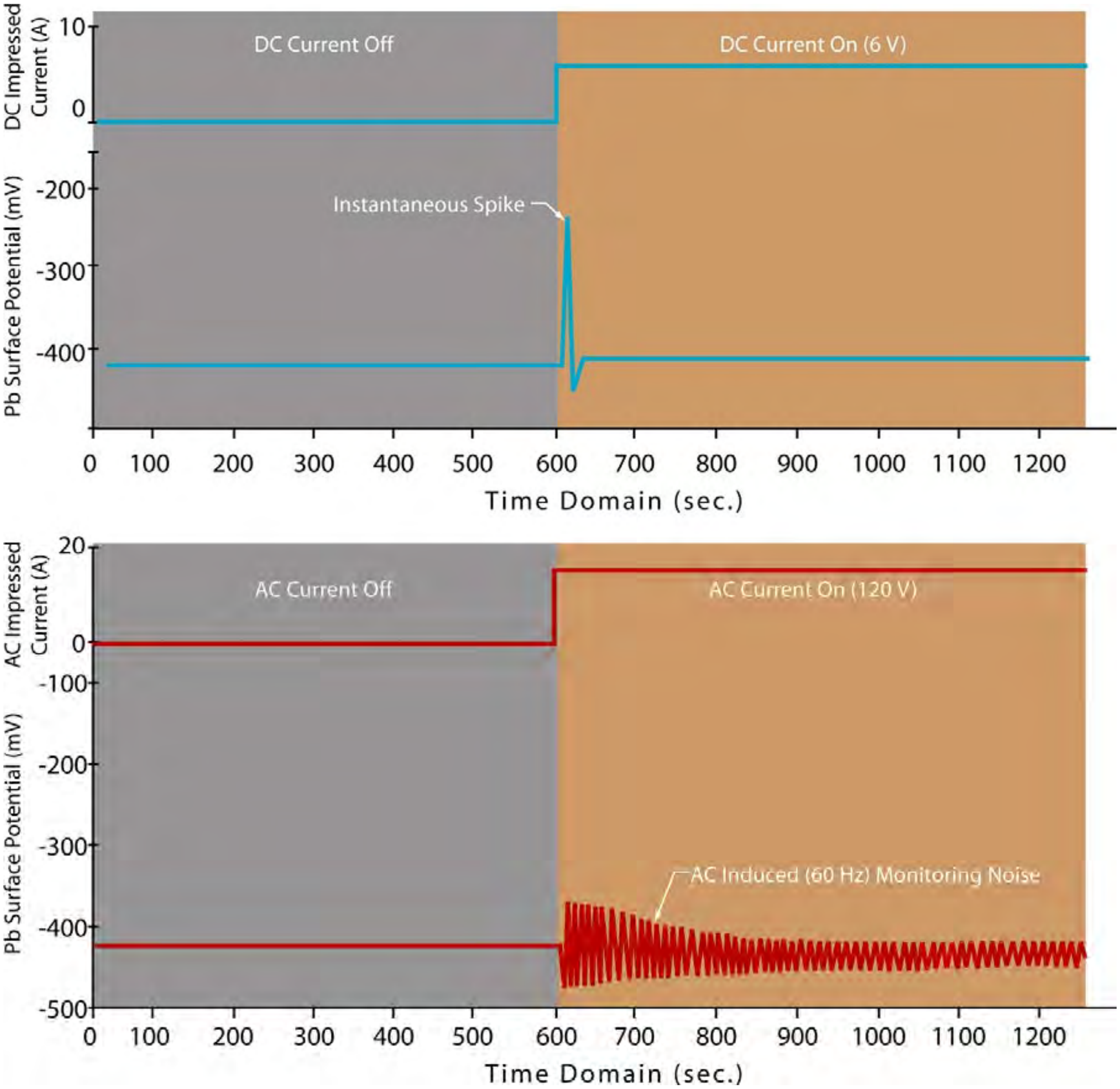


Figure 37. Impressed current impacts for separate DC (upper) and AC (lower) tests on surface potential of a lead service line coupled to copper tubing

Table 19. Summary evaluation of data and information – grounding currents that affect corrosion of lead-bearing components

Data and Information Considered	Evaluation of Data and Information Pertaining to this Possible Cause
Reiber and Dufresne (2005)	Laboratory testing results indicate that grounding currents on lead service lines and copper service lines had no discernable impacts on the internal corrosion of the household service lines or any other plumbing appurtenance that were tested.

5.10 City-Wide Meter Replacement Program

From March 2002 through May 2005, more than 116,000 meters were replaced in the DCWASA system by contractors (data from Raymond Hanesworth, DCWASA). This meter replacement program could be a potential cause of lead release into the drinking water in two ways: (1) soluble lead release from the meters themselves; and/or (2) disturbance of connective piping that could release and expose lead-bearing scales.

Keefer and Giani (2005) conducted a laboratory study from April to June 2004 to evaluate lead release from two new bronze water meters and subsequent uptake by water. Three different water treatment strategies were tested: free chlorine disinfection, chloramine disinfection, and chloramine disinfection with orthophosphate addition. The tap water used in the study contained lead levels that were less than 2 µg/L. Lead levels were measured after water was held in the meters for various stagnation periods ranging from 15 minutes to 23 hours. All three water treatment strategies resulted in some lead release by the meter and uptake by the water as summarized in Table 20.

Table 20. Lead release from bronze water meters in laboratory study

Water Treatment Strategy	**Lead Levels after Stagnation Period (µg/L)**	**Stagnation Periods Used (hrs)**
Free chlorine disinfection	14-165	0.25-21
Chloramine disinfection	20-145	0.5-23
Chloramine + orthophosphate	2-22	0.5-18

Source: Keefer and Giani (2005)

The results of this study suggest that bronze meters may contribute to elevated lead levels in drinking water (Keefer and Giani, 2005). However, lead profiles were used by Keefer and Giani (2005) to illustrate why lead release from bronze meters may in fact not substantially increase lead levels in samples collected at residential taps. This conclusion was based on the following: dilution effects from the meter to the tap; dilution effects during sample collection; and the age of the bronze meter. There is little other data available on the potential release of lead and the contribution to lead levels at the tap associated with meter replacement. Based on currently available data and information, the contribution of lead by the city-wide meter replacement programs is small and likely not a major contributor to lead levels at the tap. Table 21 is a summary evaluation of data and information related to the city-wide meter replacement program.

Table 21. Summary evaluation of data and information – city-wide meter replacement program

Data and Information Considered	**Evaluation of Data and Information Pertaining to this Possible Cause**
Keefer and Giani (2005)	Laboratory testing results indicate that bronze meters could contribute lead levels to drinking water. However, the contribution of lead is likely not substantial due to dilution effects (in plumbing and in the sampling container) and the age of the bronze meter.

5.11 Drought Conditions and Effects on Corrosivity of DCWASA Water

Two periods of drought conditions have occurred in recent years in the Washington, D.C. area. From the fall of 1998 through the early summer of 1999, lower than normal rainfall contributed to drought conditions in the Potomac River basin (Steiner and Hagen, 2000). From the fall of 2001 through the summer of 2002, below normal rainfall and record low groundwater levels and stream flows were observed (Kiang and Hagen, 2004).

Available source water quality data were reviewed for the period of January 1998 through September 2004 to compare water quality conditions during the aforementioned drought periods (fall 1998 to summer 1999 and fall 2001 to summer 2002) and the interim period (fall 2000 to summer 2001). A limited review of source water-specific conductance and alkalinity data, collected on a monthly basis and summarized in Table 22, shows no obvious differences between the drought periods and the period with assumed normal precipitation.

Table 22. Source water quality data (1998 through 2000)

Period	**Specific Conductance (μS/cm)[a]**		**Alkalinity (mg/L as $CaCO_3$)[b]**		**Temperature (°F)[b]**	
	Average	**Range**	**Average**	**Range**	**Average**	**Range**
Jan 1998 – Aug 1998	ND	ND	97	83-106	61	38-85
Sep 1998 – Aug 1999 (Drought)	315	233-371	109	69-132	60	31-88
Sep 1999 – Aug 2001	300	195-405	81	64-108	60	33-85
Sep 2001 – Aug 2002 (Drought)	340	204-454	73	30-117	63	35-87
Sep 2002 – Dec 2004	339	273-392	62	40-95	53	33-78

ND – No data available.

a Untreated source water data.

b Entry point data collected at McMillan Water Treatment Plant. Similar alkalinity and water temperature values were observed for the Dalecarlia plant.

Figure 38 shows the average daily conductivity of water at the distribution system entry points during the two drought periods reported from January 1998 through December 2004. It was assumed that a drought could cause an increase in conductivity during low rainfall periods as a result of reduced dilution effects. The data shown in Figure 38 do not show a clear indication that the conductivity of water entering the distribution system increased or decreased substantially during the drought periods relative to non-drought periods.

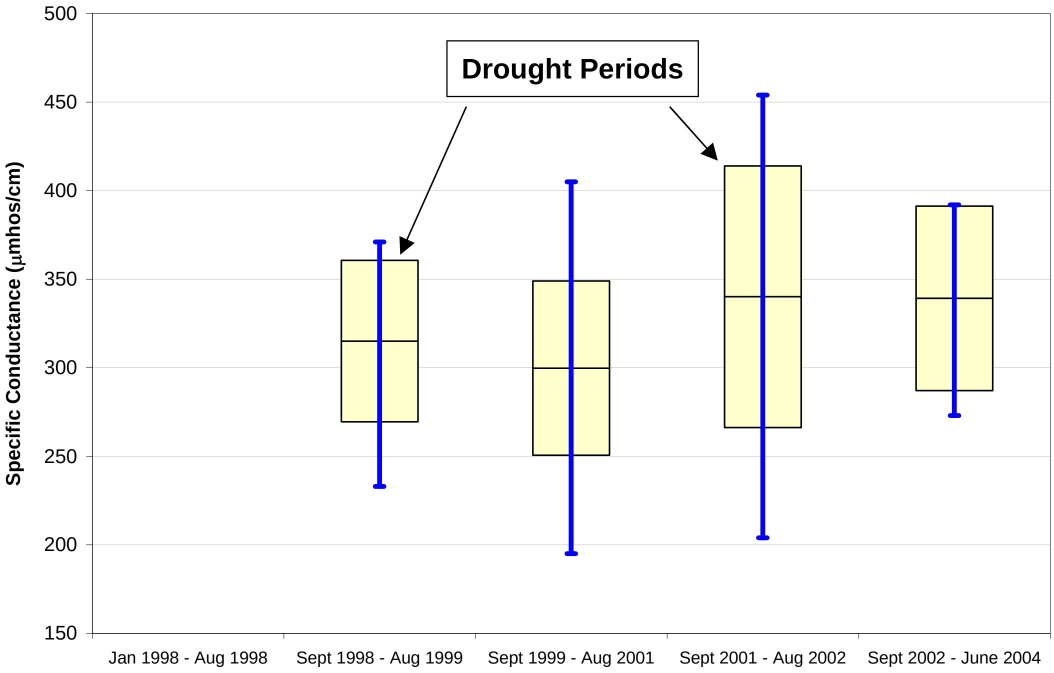


Figure 38. Average daily specific conductance of water at the distribution system entry points during drought periods

The average daily alkalinity for water at the distribution system entry points is shown in Figure 39. During the first drought period, alkalinity increased relative to that measured in the preceding period; however, alkalinity was lower during the second drought period. In fact, the average alkalinity values showed a decreasing trend following the drought which occurred during 1998-1999. Thus, these data do not indicate a clear relationship between finished water alkalinity and drought conditions.

The average daily finished water temperature at the distribution system entry points is shown in Figure 40. From the data shown here the average finished water temperature did not differ substantially during the two drought periods relative to the non-drought ones. Indeed, periods of drought do not have to necessarily correspond to periods of elevated air temperatures. Instead drought is a measure of precipitation. Similar to other parameters, these data do not show a clear indication of a meaningful change in temperature which could impact the corrosion potential of water entering the distribution system.

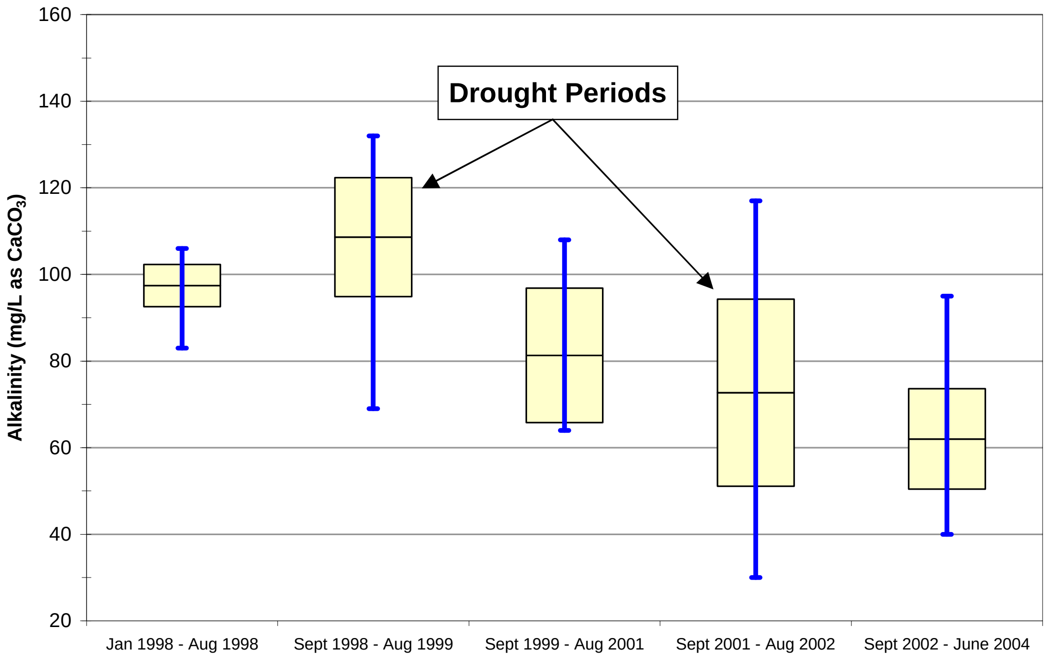


Figure 39. Average daily alkalinity of water at the distribution system entry points during drought periods

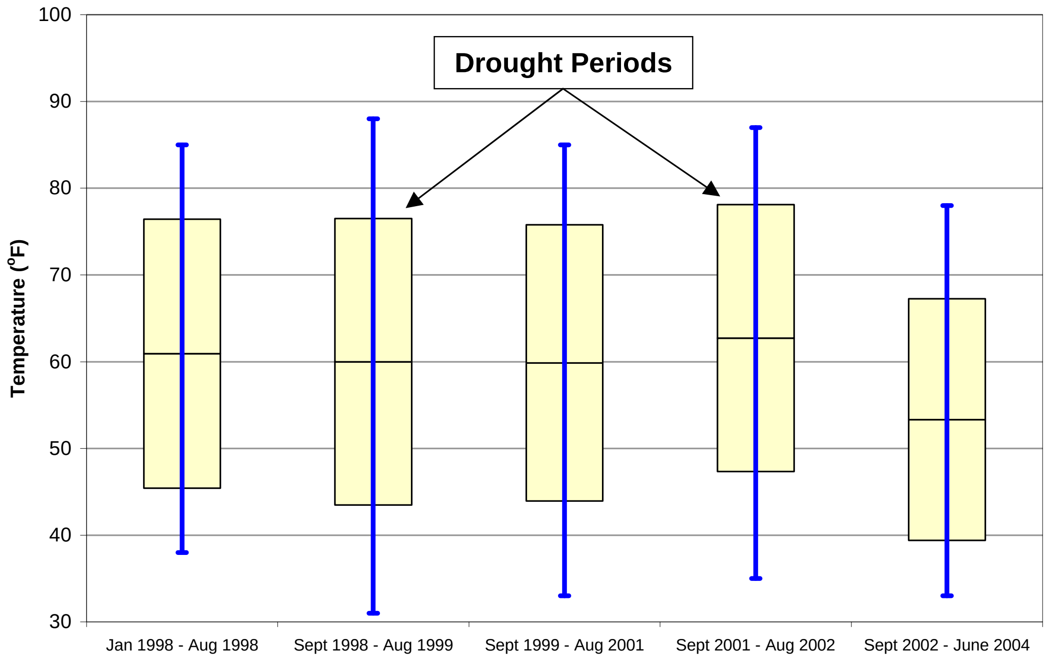


Figure 40. Average daily temperature of water at the distribution system entry points during drought periods

Drought conditions may also quantitatively and qualitatively affect the concentrations and characteristics of NOM entering raw water systems (Volk et al., 2002; Maurice et al., 2001). These changes result from changes in the amount and origin of the water that enters a surface water system. For instance, during drought periods there is less surface water runoff, and in turn a greater portion of the river's base flow is groundwater seepage. The organic loading rate to a river may be lower during drought periods and may thus exert a lower chlorine demand compared to non-drought periods. The limited amount of water quality data (entry point and average distribution system free chlorine concentrations) that was available for the DCWASA system did not indicate that this was the case during the two drought periods and did not show any difference relative to the non-drought periods. This cannot be directly linked to the amount of NOM entering the DCWASA distribution system, as no data was available on the concentration or character of these organics. However, it is likely that any changes in NOM concentrations that occurred during the drought periods were not significant enough to dramatically alter the chlorine demand or in turn the ORP of the finished water.

Based on available source water quality data and the data evaluation discussed above, results do not implicate drought as a major factor in causing lead release. This conclusion is based on the observations that the noted water quality parameters, which may affect corrosion rates, did not change appreciably during the two drought periods relative to non-drought ones. These observations are summarized in Table 23.

Table 23. Summary evaluation of data and information – drought conditions and their effect on corrosivity of DCWASA water

Data and Information Considered	Evaluation of Data and Information Pertaining to this Possible Cause
Steiner and Hagen (2000) Kiang and Hagen (2004) HDR/EES analysis of DCWASA lead data for LCR compliance, 1998 – 2004. HDR/EES analysis of available data for specific conductance, alkalinity, and temperature, 1998 – 2004.	Data yields no definitive trend. Drought conditions likely were not a major contributor to elevated lead levels.

6. CURRENT STATUS OF DCWASA SYSTEM AND POSSIBLE FOLLOW-ON WORK

This section provides a brief summary of the current LCR compliance status of the DCWASA system. In addition, this section identifies possible follow-on work based on available findings and conclusions drawn from this study.

6.1 Current LCR Compliance Status of DCWASA System

DCWASA, in conjunction with the USEPA and WA, has been conducting a series of studies aimed at: (1) determining the possible cause(s) of high lead levels since LCR compliance monitoring in July 2000 - June 2001; and (2) identifying solutions to reduce and control lead levels at consumers' taps. As part of these studies, DCWASA conducted a partial system application of orthophosphate in a portion of the distribution system known as the 4th High Pressure Zone beginning June 1, 2004. Based on results of this demonstration test, orthophosphate was subsequently added as treatment at the WA water treatment facilities to cover the entire DCWASA system beginning August 23, 2004 for the purpose of lowering lead levels at the tap.

The OCCT designation was modified and clarified on August 3, 2004 and September 8, 2004 to consist of application of orthophosphate subject to stated conditions and water quality parameters (source: correspondence from USEPA Region 3 to WA and DCWASA dated August 3, 2004). USEPA Region 3 stipulated that WA meet a pH range of 7.7±0.3 for finished water leaving both water treatment plants during the distribution system passivation period. A goal of 7.7±0.1 was set, although this pH range was not enforceable. For distribution system samples, the same enforceable pH range (7.7±0.3) and non-enforceable pH goal (7.7±0.1) applied to DCWASA.

Based on recent compliance monitoring information (DCWASA 2005; 2006), DCWASA was below the LCR lead action level for two consecutive 6-month monitoring periods in 2005 since commencing system-wide addition of orthophosphate in August 2004.

6.2 Possible Follow-on Evaluation

Follow-on evaluations could be conducted for the purpose of understanding further factors that contributed to the occurrence of elevated lead levels at consumers' taps in the DCWASA system. In addition, follow-on evaluations could be conducted for the purpose of enhancing current understanding of the interrelationships of water chemistry and scales on metals release in drinking water systems. Additional work activities that could address these issues are described below.

6.2.1 DCWASA-Related Follow-on Evaluations

This section outlines suggested follow-on evaluations aimed at providing further clarification with regard to specific conditions and events that contributed to elevated lead levels in the DCWASA system. Suggested topics include the following:

- Reduced pH and alkalinity in distributed water during 2001 – 2002

- Consequences of partial and full LSL replacement

6.2.1.1 Reduced pH and Alkalinity in Distributed Water during 2001 – 2002

The pH and alkalinity of finished water at the Dalecarlia and McMillan plants exhibited seasonal variations and fluctuations during the study period from 1992 to 2004. The pH and alkalinity of the distributed water generally followed the seasonal variations of the finished water, except during 2001 – 2002 when the pH and alkalinity of the distributed water were notably lower than the finished water discharged at the plants. The occurrence of nitrification in the distribution system has not been documented by DCWASA or USEPA Region 3 (Rizzo, 2005b). More research is therefore needed to understand the cause of reduced pH and alkalinity in the distributed water during 2001 – 2002 and its possible impacts on lead release and corrosion control in the DCWASA system.

6.2.1.2 Consequences of Partial and Full LSL Replacement

DCWASA has replaced a large number of lead service lines in the service area. Data gaps exist regarding the effectiveness of partial lead service line replacement programs on reducing lead levels at consumers' taps, and whether there are any short- or long-term negative impacts such as elevated lead spikes or disturbance of existing scales. This suggested follow-on work could improve understanding of the impact and consequences of performing partial or full lead service replacements on lead release and compliance with the LCR.

6.2.2 Research to Enhance Understanding of Lead Release

This section identifies follow-on evaluations that could enhance understanding of lead release associated with a change in treatment and potentially could be applicable to other utility situations. These suggested topics include the following:

- Lead release in analogous systems following disinfectant change
- Effectiveness of orthophosphate on lead scales
- Effects of chloride and sulfate levels on lead release under chlorination, chloramination, and a disinfectant change
- Characterization of ORP as a function of disinfection regime and ORP impact on lead scales
- Improved understanding of the mechanisms and factors influencing the formation of Pb (IV) scales
- Impact of changes in treatment processes on lead scale formation and lead release

6.2.2.1 Lead Release in Analogous Systems following Disinfectant Change

This report considered the importance of the complex interrelationships of ORP and pH on the predominance of Pb (II) or Pb (IV) in scales, and ultimately the release of lead from LSL during a change in disinfectant in the DCWASA system. Aspects of these interrelationships have been considered as contributing factors in metals release at other systems such as Greater Cincinnati Water Works and City of Madison Water Utility

(Schock et al., 2001; Lytle and Schock, 2005b). Further analysis of analogous drinking water systems could be conducted by developing case studies to understand the complex interrelationships of these water quality parameters and system conditions on metals release associated with a change in disinfectant.

6.2.2.2 Effectiveness of Orthophosphate on Lead Scales

This report addresses the timeframe prior to system-wide application of orthophosphate inhibitor for corrosion control (i.e., prior to August 2004). Current information about orthophosphate effectiveness is based primarily on the presence and behavior of Pb (II) species. Little information is currently available regarding interactions of orthophosphate with Pb (IV) species. Consequently, it is difficult to predict the impact of using orthophosphate for corrosion control during a transition between Pb (II) and Pb (IV) regimes or under conditions in which Pb (IV) is the dominant species. More research is needed to understand the interaction of orthophosphate with different lead species and corrosion scales.

6.2.2.3 Effects of Chloride and Sulfate Levels on Lead Release under Chlorination, Chloramination, and a Disinfectant Change

The impact of the chloride and sulfate ratio on lead release is a topic that has not been investigated for the DCWASA system, primarily because data were not available. This topic is an area that warrants additional study to understand further the multiple and competing factors, in conjunction with a disinfectant change, that impact lead release.

Chloride increases lead corrosion while sulfate appears to mitigate the corrosive effects of chloride. Consequently, the chloride/sulfate ratio is recognized as an important parameter in lead corrosion studies (Reiber et. al, 1997). Recent research, including studies pertaining to both free chlorine and chloramines disinfection, also demonstrates a correlation between chlorides, sulfates and lead release (Taylor et al., 2005; Tang et al., 2006).

Proposed further work could include reviewing relevant data, if available, from other systems that use water from Washington Aqueduct such as Fairfax and Arlington.

6.2.2.4 Characterization of ORP as a Function of Disinfection Regime and ORP Impact on Lead Scales

There are data gaps in understanding the importance of ORP under different disinfection regimes as discussed in Section 5. More information is needed about ORP conditions in actual systems before, during, and after disinfectant changes. More information is also needed on how changes in ORP increase or decrease metals release. Improved understanding of the role of ORP on lead scale formation, passivation and water chemistry conditions could provide utilities with needed operational information for improved control of metals release.

6.2.2.5 Improved Understanding of the Mechanisms and Factors Influencing the Formation of Pb (IV) Scales

The mechanisms of Pb (IV) formation are not well understood, as described previously in this report. For example, Switzer et al. (2006) highlighted data gaps in the mechanisms of PbO_2 formation. Lytle and Schock (2005b) identified the need for more research to determine the ORP threshold for PbO_2 stability, its solubility in relation to pH, and the relationship to disinfectant type, residual, and oxidant demand in the pipe scale. . Korshin et al. (2005) discussed the influence of natural organic matter on corroding lead materials. Further fundamental research in these areas could enable a better understanding of the conditions that most likely facilitate and maintain Pb (IV) formation in drinking water systems.

6.2.2.6 Impact of Changes in Treatment Processes on Lead Scale Formation and Lead Release

More research on the formation and stability of Pb (IV) scales under a variety of different conditions is needed. Lytle and Schock (2005b) identified the need for elucidating the decomposition pathway of PbO_2 scales because serious problems potentially could occur with treatment changes that result in lowering of the redox potential. Additional research is therefore needed to understand how temporary and long-term changes in disinfectant affect the formation of lead scale and short- and long-term lead release at consumers' taps. Other possible treatment changes such as pH adjustment and coagulant changes could potentially affect scales formation and stability. This information could form the basis for developing decision-tools that utilities could use to predict how treatment changes and chemical conditions will impact lead scales and lead release.

7. ABBREVIATIONS

µg/L	micrograms per liter
AC	alternating current
AL	action level
AO	Administrative Order
DC	District of Columbia (or direct current)
DCWASA	District of Columbia Water and Sewer Authority
DS	distribution system
EC	electrochemical
GIS	Geographic Information Systems
LCR	Lead and Copper Rule
LSI	Langelier Saturation Index
LSL	lead service line
LSLR	lead service line replacement
MCL	maximum contaminant level
mg/L	milligrams per liter
NE	northeast
NOM	natural organic matter
NSF	National Sanitation Foundation
NW	northwest
O&M	operations and maintenance
OCCT	Optimal Corrosion Control Treatment
ORP	Oxidation Reduction Potential
OWQP	Optimal Water Quality Parameters
PbO_2	lead dioxide
PLSLR	partial lead service line replacement
PO_4	phosphate
POU	point-of-use
ppb	parts per billion
ppm	parts per million
PQAPP	Programmatic Quality Assurance Project Plan
SE	southeast
SHE	standard hydrogen electrode
SOP	standard operating procedures
SW	southwest
SWTR	Surface Water Treatment Rule
TCR	Total Coliform Rule
THM	trihalomethane
TTHM	total trihalomethane
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
WA	Washington Aqueduct
WASUA	Water and Sewer Utility Administration
WTP	water treatment plant
WWTP	wastewater treatment plant

8. REFERENCES

AWWA (American Water Works Association). 2005. Managing Change and Unintended Consequences: Lead and Copper Rule Corrosion Control Treatment. Denver, CO.

AwwaRF. 1990. *Lead Control Strategies.* Awwa Research Foundation and American Water Works Association. Denver, CO.

AwwaRF. 1996. Electrical Grounding, Pipe Integrity and Shock Hazard. American Water Works Association. Denver, CO.

Bell, G.E.C. 1998. Observation on the effect of grounding on water piping. Corrosion (95), Orlando, FL.

Boyd, G.R., P. Shetty, A.M. Sandvig, and G.L. Pierson. 2004. Pb in tap water following simulated partial lead pipe replacements. *J. Environ. Eng.* 130(10): 1188-1197.

Boyd, G.R., K.M. Dewis, A.M. Sandvig, G.J. Kirmeyer, S.H. Reiber, and G.V. Korshin. 2006a. *Effect of Changing Disinfectants on Distribution System Lead and Copper Release, Part 1: Literature Review*, Awwa Research Foundation. Denver, CO.

Boyd, G.R., G.L. Pierson, G.J. Kirmeyer, M.D. Britton, and R.J. English. 2006b. Pb Release from End-Use Plumbing Components. In *Proc. of the AWWA Water Quality Technology Conference*, November 2006. Denver, CO.

Cantor, A.F., J.K. Park, and P. Vaiyavatjamai. 2003. Effect of Chlorine on Corrosion in Drinking Water Systems. *Journal AWWA*, 95(5) 112-123.

CH2MHILL. 2004. Desktop Corrosion Control Study. Prepared for USEPA Region 3. Philadelphia, PA. April 2004.

Clement, J.A. 1996. Review of Washington, D.C. Corrosion Control Recommendations. Peer review of Corrosion Control Study (1996). Sent to G. Rizzo, USEPA Region 3, December 13, 1996.

Colling, J.H., Whindcup, P.A.E., and C.R. Hayes. 1987. The measurement of plumbosolvency propensity to guide the control of lead in tapwaters. *Journal of the Institute of Water and Environmental Management*, 1(2): 263-269.

DCWASA. 2003. Annual Report for the 2003 Lead Service Replacement Program. September 2003.

DCWASA. 2004. Update of the Annual Report for the 2004 Lead Service Replacement Program. October 8, 2004.

DCWASA. 2005. Lead & Copper Compliance Report, January – June 2005, October 14, 2005.

DCWASA. 2006. Lead & Copper Compliance Report, July – December 2005, May 3, 2006.

ECG, Incorporated. 1994. Corrosion Control Study. Study for the Mobile District, U.S. Army Corps of Engineers, June 2004.

Edwards, M. 2003. Letter sent to G. Rizzo, USEPA Region 3, October 17, 2003.

Edwards, M. and A. Dudi. 2004. Role of chlorine and chloramines in corrosion of lead-bearing plumbing materials. *Journal AWWA* 96(10): 69-81.

Gardels, M.C. and T.J. Sorg. 1989. A laboratory study of the leaching of lead from water faucets. *Journal AWWA* 81(7): 101.

Giani, R., M. Edwards, C. Chung, and J. Wujek. 2005a. Use of lead profiles to determine source of action level exceedances from residential homes in Washington, D.C. Internal Report for DCWASA.

Giani, R., M. Donnelly, and T. Ngantcha. 2005b. The effects of changing between chloramine and chlorine disinfectants on lead leaching. In *Proc. of the AWWA Water Quality Technology Conference*, November 2005, Québec City, Québec, Canada.

Grumbles, B. 2004. Memorandum to Regional Administrators – Water Division Directors – Regions I–X: Lead and Copper Rule – Clarification of Requirements for Collecting Samples and Calculating Compliance. November 23, 2004. Washington, D.C.

Hopwood, J.D., Davey, R.J., Jones, M.O., Pritchard, R.G., Cardew, P.T., and A. Booth. 2002. Development of chloropyromorphite coatings for lead copper pipes. *Journal of Materials Chemistry*, 12(6): 1717-1723.

International Studies and Training Institute Inc. (ISTI). 1995. Final Report: Sanitary Survey of the Drinking Water Distribution System of the District of Columbia. Appendix A, p.13–15.

Keefer, W. and R. Giani. 2005. Lead investigation: bronze water meters. Internal Report for AwwaRF Project 3018. Washington, D.C.: DCWASA Water Quality Division.

Khanal, S.C., Shang, C., and Huang, J.C. 2003. Use of ORP (oxidation reduction potential) to control oxygen dosing for online sulfide oxidation in anaerobic treatment of high sulfate wastewater. Water Science Technology 47(12): 183-189.

Kiang, J.E. and E.R. Hagen. 2004. Preparing for extreme droughts: moving beyond the historical planning event in the Potomac Basin. In *Proc. of the World Water and Environmental Resources Congress,* sponsored by ASCE EWRI, Salt Lake City, UT, June 27 – July 1, 2004.

Kirmeyer, G.J., G.R. Boyd, N.K. Tarbet, R. Serpente. 2000. Lead Pipe Rehabilitation and Replacement Techniques. 176-177. Awwa Research Foundation. Denver, CO.

Korshin, G.V., J.F. Ferguson, and A.N. Lancaster. 2005. Influence of natural organic matter on the properties of corroding lead surface and behavior of lead-containing particles. *Water Research,* 39(5): 811-818.

Lin, N.H., A.Torrents, A.P. Davis, and M. Zeinali. 1997. Lead corrosion control from lead, copper-lead solder, and brass coupons in drinking water employing free and combined chlorine. *Journal Environ Sci Health* A32(4) 865-884.

Lytle, D.A. and M.R. Schock. 2000. Impact of stagnation time on metal dissolution from plumbing materials in drinking water. *Journal of Water Supply: Research and Technology* (49) 5: 243-257.

Lytle, D.A. and M.R. Schock. 2005a. The formation of Pb (IV) oxides in chlorinated water. In *Proc. of the AWWA Water Quality Technology Conference*. November 2005, Québec City, Québec, Canada.

Lytle, D.A. and M.R. Schock. 2005b. Formation of Pb (IV) oxides in chlorinated water. *Journal AWWA* 97(11): 102-114.

Malcolm Pirnie Inc. 1998a. Caustic Soda Feasibility Study for Dalecarlia and McMillan Water Treatment Plants. Prepared for WA U.S. Army Corps of Engineers, Baltimore District.

Malcolm Pirnie Inc. 1998b. Corrosion Inhibitor Study for Dalecarlia and McMillan Water Treatment Plants. Prepared for WA U.S. Army Corps of Engineers, Baltimore District.

Marani, D., G. Macchi, and M. Pagano. 1995. Lead Precipitation in the Presence of Sulphate and Carbonate: Testing of Thermodynamic Predictions. *Water Resources* (29): 1085-1092.

Maurice, P.A., Cabaniss, S.E., and Drummond, J. 2001. Climate induced changes in the chemical characteristics of natural organic matter at a small freshwater wetland, American Geophysical Union, Fall Meeting 2001. Abstract # B22C-0150.

Moser, M.R. 2006. Personal correspondence via e-mail on May 10, 2006 from M. Rome Moser of Environomics to G. Boyd of HDR/EES, with spreadsheet attachment entitled “Appendix graphs.xls” containing lead profile data collected in the DCWASA system.

Odom, R. 2006a. Environomics Personal Communication via e-mail to G. Boyd of HDR/EES, 07/27/2006, with document attachment entitled “EPA comments.doc” containing lead profile data collected in the DCWASA system 2004-2006.

Odom, R. 2006b. Environomics Personal Communication via e-mail to G. Boyd of HDR/EES, 07/27/2006, with spreadsheet attachment entitled “4th high sample analysis 7_28_04 (2).xls” containing WQP data collected in the DCWASA system in the 4th High Pressure Zone, 4/5/2004 through 7/6/2004.

Reiber, S., S. Poulsom, S. Perry, M. Edwards, S. Patel, and D. Dodrill. 1997. General Framework for Corrosion Control Based on Utility Experience. Awwa Research Foundation. Denver, CO.

Reiber, S. and L. Dufresne. 2005. Effects of external currents and dissimilar metal contact on corrosion from lead service lines, draft final report prepared for USEPA Region 3. November 2005.

Reiber, S. and R. Giani. 2005. National impacts from DC’s lead experience. In *Proc. of WEFTEC*, Washington, D.C., Water Environment Federation, 5994-6014.

Rizzo, G. 2004. USEPA Region 3 / DCWASA Response: Recommendations from Marc Edwards’ Review of Corrosion Control Treatment for the District of Columbia Water System, October 17, 2003, Spring 2004.

Rizzo, G. 2005a. Personal communication via e-mail from George Rizzo, USEPA Region 3, to Kathy Martel, HDR/EES. May 9, 2005.

Rizzo, G. 2005b. Personal communication via e-mail from George Rizzo, USEPA Region 3, to Kathy Martel, HDR/EES. March 30, 2005.

Rizzo, G. 2006a. Personal communication via e-mail from G. Rizzo, USEPA Region 3, to G. Boyd, HDR/EES. May 9, 2006.

Rizzo,G. 2006b. USEPA Region 3. USEPA/HDR conference call September 7, 2006.

Rizzo, G. 2006c. Personal communication via e-mail from G. Rizzo, USEPA Region 3, to K. Smith, USEPA, Washington D.C. September 28, 2006.

Samuels, E.R. and J.C. Meranger. 1984. Preliminary studies on the leaching of some trace metals from kitchen faucets. *Water Research* 18(1): 75.

Schock, M.R. 1999. Internal corrosion and deposition control. Chapter in *Water Quality and Treatment: A Handbook of Community Water Supplies*, Fifth Edition. American Water Works Association: McGraw Hill, New York, NY.

Schock, M.R. 2005. Lead chemistry basics, scale formation, and corrosion control treatment. *Virginia Section of AWWA Drinking Water Quality Seminar.* April 13, 2005, Richmond, VA.

Schock, M.R. I. Wagner and R.J. Oliphant. 1996. Corrosion and Solubility of Lead in Drinking Water. Chapter 4 in Internal Corrosion of Water Distribution Systems. Second Edition. American Water Works Association Research Foundation and DVGW-Technologiezentrum Wasser. Denver, CO.

Schock, M.R., S.M. Harmon, J. Swertfeger, and R. Lohmann. 2001. Tetravalent lead: a hitherto unrecognized control of tap water lead contamination. In *Proc. of the AWWA Water Quality Technology Conference*. Denver, CO.

Schock, M.R. and C.H. Neff. 1988. Trace metal contamination from brass fittings. *Journal AWWA* 80(11): 47.

Schock, M.R. and R. Giani. 2004. Oxidant/disinfectant chemistry and impacts on lead corrosion. *Sunday Workshop, AWWA Water Quality Technology Conference*.

Schock, M.R., K. Scheckel, M. DeSantis, and T. Gerke. 2005. Mode of occurrence, treatment, and monitoring significance of tetravalent lead. In *Proc. of AWWA Water Quality Technology Conference.* November 2005, Québec City, Québec, Canada.

Smith, K. 2006. Personal communication via e-mail from K. Smith, USEPA Washington, D.C., to G. Boyd, HDR/EES, July 27, 2006.

Smith, K. 2007. Personal communication via e-mail from K. Smith, USEPA Washington, D.C., to G. Boyd, HDR/EES, April 26, 2007.

StatSoft. 2006. Electronic Statistics Textbook, Web site accessed on May 23, 2006. http://www.statsoft.com/textbook/stathome.html.

Steiner, R.C. and E.R. Hagen. 2000. Urban drought planning vs. the real thing. In *ASCE Water Resources*.

Switzer, J.A., V.V. Rajasekharan, S. Boonsalee, E.A. Kulp, and E.W. Bohannan. 2006. Evidence that monochloramine could lead to elevated Pb levels in drinking water. *Environ. Sci. Technol.* 40(10): 3384-3387.

Symons, J.M., L.C. Bradley, Jr., and T.C. Cleveland. 2000. The Drinking Water Dictionary. American Water Works Association.

Tang, Z., S. Hong, W. Xiao, and J. Taylor. 2006. Impacts of blending ground, surface and saline waters on lead release in drinking water distribution systems, *Water Research* 40: 943-950.

Taylor, J., J. Dietz, A. Randall, S. Hong. 2005. Impact of RO-desalted water on distribution water qualities. *Water Science & Technology* 51(6-7): 285-291.

U.S. Army Corps of Engineers (USACE). 2006. Washington Aqueduct, Baltimore District, Web site accessed on September 25, 2006. http://washingtonaqueduct. nab.usace.army.mil/.

USEPA. 1991. Drinking Water Regulations; Maximum Contaminant Level Goals and National Primary Drinking Water Regulations for Lead and Copper; Final Rule. 40 CFR, parts 141 and 142. 56 *Federal Register* No. 110, June 7, 1991.

USEPA. 2000. Letter from USEPA, Jon M. Capacasa, to Thomas P. Jacobus, Chief Washington Aqueduct, designating pH adjustment as OCCT. February 29, 2000.

USEPA Region 3. 2004a. Administrative Order for Compliance on Consent issued to DCWASA on Lead Service Line Replacements. June 17, 2004.

USEPA. 2004b. 4th High Pressure Zone – Washington, D.C. http://www.epa.gov/dclead/4th_zone_bnd.pdf . Web site accessed September 28, 2006.

USEPA. 2006. Corrosion Control. http://www.epa.gov/dclead/corrosion.htm. Web site accessed September 28, 2006.

Van den Hoven, T.J. 1987. A new method to determine and control lead levels in tap water*.* *Aqua* (6): 315-327.

Vasquez, F.A., R. Heaviside, Z. Tang, and J. Taylor. 2006. Effect of free chlorine and chloramines on lead release in a distribution system. *Journal AWWA* 98(2): 144-154.

Volk, C., Wood, L., Johnson, B., Robinson, J., Zhu, H.W., and Kaplan, L.. 2002. Monitoring dissolved organic carbon in surface and drinking waters J. Environ. Monit., 2002, 4, 43 – 47.

White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants, 4th ed., p. 965.

Wujek, J.J. 2005. Minimizing peak lead concentrations after partial lead service replacements. Internal Report for AwwaRF Project 3018. Baker Killam Joint Venture.

Appendix A

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Timeline

July 1992
District of Columbia Water and Sewer Authority (DCWASA) exceeded the lead action level for the Jan. to June 1992 monitoring period, the first required round of Lead and Copper Rule (LCR) compliance monitoring (source: July 16, 1997 correspondence from USEPA Region 3 to DCWASA).

January 1993
District of Columbia Water and Sewer Authority (DCWASA) exceeded the lead action level for the July to December 1992 monitoring period, the second required round of LCR compliance monitoring (source: July 16, 1997 correspondence from USEPA Region 3 to DCWASA).

September 29, 1993
Administrative Order (AO) issued to Water and Sewer Utility Administration (WASUA) for acute and routine violations of the Total Coliform Rule (TCR) in September 1993. WASUA was required to submit a plan for improving the flushing program.

October 15, 1993
AO issued to the Washington Aqueduct (WA) for "virtual" violation of the TCR, i.e., numerous coliform positive samples at the entry points to the distribution system.

December 7, 1993
Turbidity MCL violation at Dalecarlia water treatment plant (source: 1995 Sanitary Survey of the Drinking Water Distribution System of the District of Columbia).

January 1994
DCWASA reported that the lead action level was exceeded for the July to Dec. 1993 monitoring period (source: CDM memo12/12/03).

March 2, 1994
AO issued to the WA due to a violation of the turbidity requirements of the Surface Water Treatment Rule (SWTR). The AO required the WA to perform a Comprehensive Performance Evaluation at the Dalecarlia and McMillan water treatment plants, and to comply with the filtration, disinfection, reporting and public notification requirements of the Safe Drinking Water Act. It also required the WA to develop a source water monitoring program, to analyze capital improvement needs at both water treatment plants, and to evaluate procedures for emergency notification of plant personnel.

June 1994
WA submitted a corrosion control report to USEPA Region 3 that recommended optimum corrosion control treatment as pH control to maintain a positive Langelier Saturation Index.

July 1994
WASUA reported that the lead action level was exceeded for the Jan. to June 1994 monitoring period (source: CDM memo12/12/03, and DCWASA 90th percentile calculations).

June 1995
WASUA recorded an acute Total Coliform Rule violation for *E. coli* (source: 1996 Follow-Up Sanitary Survey of the Drinking Water Distribution System of the District of Columbia).

October 1995
WASUA violated the TCR MCL (more than 5% of samples were total coliform positive) (source: 1996 Follow-Up Sanitary Survey of the Drinking Water Distribution System of the District of Columbia).

November 1995
WASUA recorded two acute violations of the TCR and USEPA Region 3 issued a limited boil water notice for the areas involved (source: 1996 Follow-Up Sanitary Survey of the Drinking Water Distribution System of the District of Columbia). Because of these events, USEPA Region 3 issued an AO that requires a rational plan of action to improve TCR compliance based on recommendations in the 1995 sanitary survey.

June 1996
WASUA violated the TCR MCL (more than 5% of samples were total coliform positive) (source: 1996 Follow-Up Sanitary Survey of the Drinking Water Distribution System of the District of Columbia).

July 1996
WASUA violated the TCR MCL (more than 5% of samples were total coliform positive) (source: 1996 Follow-Up Sanitary Survey of the Drinking Water Distribution System of the District of Columbia).

July 12, 1996
AO issued to WASUA which incorporated the November 1995AO and the routine monthly TCR violation in June 1996.

August 1996
WASUA violated the TCR MCL (more than 5% of samples were total coliform positive) (source: 1996 Follow-Up Sanitary Survey of the Drinking Water Distribution System of the District of Columbia).

July 16, 1997
USEPA Region 3 conditionally designated Optimized Corrosion Control Treatment (OCCT) as maintenance of a slightly positive Langelier Saturation Index through pH adjustment (source: correspondence from USEPA Region 3 to WA and DCWASA 7/16/97). As a condition of this designation, USEPA Region 3 issued an AO for WA and DCWASA to jointly assess the feasibility of alternate corrosion control treatment including use of sodium hydroxide for pH control, and use of a non-zinc orthophosphate corrosion inhibitor.

October 1, 1996
DCWASA was created (note no longer named WASUA).

February 2000
USEPA Region 3 designated the use of pH adjustment as the OCCT for the Washington Aqueduct and DCWASA. This designation required WA to maintain the highest pH level attainable at the entry points to the distribution system without causing excessive calcium carbonate precipitation in the distribution system. USEPA Region 3 designated that a minimum pH of 7.7 be maintained at the entry points to the distribution system and at all tap samples within the distribution system (source: correspondence from USEPA Region 3 to WA and DCWASA 2/29/00). USEPA Region 3 also reduced the requirement for LCR tap monitoring to once per year at 50 sites during the period June-September.

DCWASA established a supplemental monitoring plan to supplement the TCR monitoring program focusing on worst-case areas (Source: 2002 Sanitary Survey).

November 1, 2000
WA initiated addition of chloramines for final disinfection in the distribution system, replacing free chlorine addition (source: CDM memo12/12/03).

November 1, 2000
WA converted from a dry alum feed system to a liquid alum feed system (source: CDM memo 12/12/03).

2000
Drought conditions may have affected source and finished water quality sufficiently to affect lead solubility (source: CDM memo12/12/03).

May 17, 2002
Retroactive to the monitoring period which began on July 1, 2000, USEPA Region 3 revised its designation of OWQP for minimum monthly pH at entry points to the distribution system as follows: January (7.7), February (7.8), March (7.7), April (7.6), May (7.5), June (7.4), July (7.4), August (7.4), September (7.4), October (7.5), November (7.5), and December (7.6). Also, the minimum pH at distribution system tap sample locations would change from 7.7 to 7.0 (source: correspondence from USEPA Region 3 to WA and DCWASA 5/17/02).

Aug. 26, 2002
DCWASA reported that more than 10% of samples exceeded the lead action level of 15 ppb for the July 1, 2001 to June 30, 2002 monitoring period (samples collected July-Aug. 2001 and June 2002) (source: correspondence from DCWASA to USEPA Region 3).

May 20, 2003
DCWASA outlined its 2003 Lead Replacement Program in a letter to USEPA Region 3. The program was accepted by USEPA Region 3 in a letter dated June 27, 2003. DCWASA was required to replace 7% of its lead services per year as long as the system continues to exceed the lead action level. In lieu of physical replacement, the regulations allow service lines to be sampled to demonstrate that the water is below the lead action level.

July 29, 2003
DCWASA reported that more than 10% of samples exceeded the lead action level for the Jan. to June 2003 monitoring period (source: correspondence from DCWASA to USEPA Region 3).

September 2003
DCWASA completed an initial inventory of lead service lines (Source: Report on the Material Evaluation and Initial Inventory Sept. 2003). As of Sept. 30, 2002, there were 23,071 known lead service lines in the DC water distribution system.

October 2003
USEPA Region 3's independent corrosion expert found no reasons for DCWASA to not implement phosphate addition for corrosion control but recommended additional studies be conducted to further diagnose the DCWASA lead problem and proposed corrective actions.

October 24, 2003
DCWASA reported that 385 lead services were physically replaced between 10/01/02 and 09/30/03, and 1,241 lead service lines were sampled in lieu of physical replacement (source: DCWASA's Lead Service Replacement Program Annual Report for 2003).

January 2004
DCWASA developed a research strategy and presented it to WA, Arlington County, The City of Falls Church, and USEPA Region 3.

January 26, 2004
DCWASA reported that more than 10% of samples exceeded the lead action level for the July to Dec. 2003 monitoring period (source: correspondence from DCWASA to USEPA Region 3).

February 2004
USEPA formed the Technical Expert Working Group to address the problem of elevated lead levels.

April 30, 2004
USEPA Region 3 designated use of zinc orthophosphate for partial system application in the 4th High Pressure Zone (source: correspondence from USEPA Region 3 to WA and DCWASA 8/3/04).

May 28, 2004
USEPA Region 3 modified its April 30, 2004 designation of OCCT for the DC distribution system to use orthophosphate instead of zinc orthophosphate for the 4th High Pressure Zone (correspondence from USEPA Region 3 to WA and DCWASA 8/3/04).

June 1, 2004
The partial system application of orthophosphate to the 4th High Pressure Zone commenced (source: correspondence from USEPA Region 3 to WA and DCWASA 8/3/04).

June 17, 2004
USEPA Region 3 issued an AO requiring DCWASA to develop a plan for updating its materials evaluation used for sampling and its inventory of lead service lines, and a plan for conducting follow-up sampling after partial replacement of a lead service line (Docket No. SDWA-03-2004-0259DS).

July 6, 2004
DCWASA exceeded the lead action level for the Jan. to June 2004 monitoring period (source: correspondence from DCWASA to USEPA Region 3).

August 3, 2004
USEPA modified the interim designation of OCCT for the DC distribution system to consist of application of orthophosphate subject to stated conditions and water quality parameters (source: correspondence from USEPA Region 3 to WA and DCWASA 8/3/04). This designation was slightly modified and clarified on September 8, 2004. USEPA stipulated that the WA meet a pH goal of 7.7 ±0.1 for finished water leaving both WTPs, and 7.7 ±0.1 for water samples from the distribution system during the passivation period.

August 23, 2004
The Washington Aqueduct began feeding an orthophosphate corrosion inhibitor (sources: DCWASA memo undated, CH2MHill pH study report 11/30/04).

September 8, 2004
The interim designation of OCCT of August 3rd 2004 was slightly modified and clarified (source: correspondence from USEPA Region 3 to WA and DCWASA 09/08/2004)

October 2004
DCWASA reported that 1,793 lead services were physically replaced between 10/1/03 and 9/30/04 (source: correspondence from DCWASA to USEPA Region 3 10/8/04).

November 30, 2004
A consultant completed a pH study report evaluating how WA can tighten pH control at the two WTPs to meet the pH goal of 7.7 +/- 0.1 pH units. The report also includes recommendations for reducing finished water turbidity at the Dalecarlia WTP (source: CH2MHill Report, 11/30/04).

January 2005
DCWASA exceeded the lead action level for the July to Dec. 2004 monitoring period (source: DCWASA Lead and Copper Compliance Report).

January 14, 2005
USEPA Region 3 issued a supplemental AO to DCWASA related to lead service line inventories, replacement program, sampling methodology and public notification. (Docket No. SDWA-03-2005-0025DS).

June 2005
DCWASA met the LCR 90th percentile AL for the monitoring period Jan-Jun 2005.

December 2005
DCWASA met the LCR 90th percentile AL for the monitoring period Jul-Dec 2005.

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Administrative Orders

The Administrative Orders (AOs) issued to the Washington Aqueduct (WA), the Water and Sewer Utility Administration (WASUA) and District of Columbia Water and Sewer Authority (DCWASA) are listed below in chronological order. WASUA was part of the District of Columbia Department of Public Works until it was replaced by DCWASA on October 1, 1996.

September 29, 1993
An Emergency AO was issued to WASUA for acute and routine violations of the TCR in September 1993. A copy is not available.

October 15, 1993
An Emergency AO was issued to the Washington Aqueduct for "virtual" violation of the TCR, i.e., numerous coliform positive samples were found at the entry points to the distribution system. The AO required application of a filter aid chemical at the McMillan water treatment plant, speciation of all fecal coliform positive samples, additional monitoring at both water treatment plants' individual filters, *Giardia* and *Cryptosporidium* monitoring at water treatment plant reservoirs, and development of a written protocol for data review. This AO was superseded by the March 1, 1994 AO.

March 1, 1994
An Emergency AO was issued to the Washington Aqueduct due to a violation of the turbidity requirements of the Surface Water Treatment Rule (SWTR). It superseded the AO dated October 15, 1993. The AO required the WA to perform a comprehensive performance evaluation at the Dalecarlia and McMillan water treatment plants, and to comply with the filtration, disinfection, reporting and public notification requirements of the Safe Drinking Water Act. It also required WA to develop a source water monitoring program, to analyze capital improvement needs at both water treatment plants, and to evaluate procedures for emergency notification of plant personnel.

November 1995
Proposed AO issued to WASUA for previous violations of the TCR and to correct deficiencies found in the 1995 sanitary survey. A copy of the final AO is not available but its content is equal to the draft AO (per G. Rizzo of USEPA Region 3 in email to K. Martel, 4/11/05).

July 12, 1996
AO issued to WASUA which incorporated the November 1995 AO. The AO required WASUA to notify the public of its November 1995 acute MCL violation and monthly MCL violations of October 1995 and June 1996. WASUA was also required to develop the following programs: public notification, financial management, flushing and disinfection, storage tank maintenance and cross connection control.

July 16, 1997

USEPA Region 3 issued an AO for WA and DCWASA to jointly assess the feasibility of alternate corrosion control treatment including use of sodium hydroxide for pH control, and use of a non-zinc orthophosphate corrosion inhibitor.

June 17, 2004

USEPA Region 3 issued an administrative order requiring DCWASA to develop a plan for updating its materials evaluation used for sampling and its inventory of lead service lines, and a plan for conducting follow-up sampling after partial replacement of a lead service line (Docket No. SDWA-03-2004-0259DS).

Jan. 14, 2005

USEPA Region 3 issued a supplemental administrative order to the June 17, 2004 order discussed above. This order indicated that DCWASA had used an unapproved and inappropriate method of five-minute flushing in determining whether some of the lead service lines needed to be replaced. This order required that DCWASA determine how many lead service lines had “passed” (meaning contributed less than 15 parts per billion of lead), as presented in the September 2003 Annual Report for Lead Service Line Replacement Program, using this incorrect methodology. Additionally, DCWASA was required to determine how many of these lines had been replaced without being reported to USEPA in 2003 and 2004. USEPA required DCWASA to physically replace lead service lines equal in number to the number of LSLs passed in the 2003 report, less the number that were physically replaced in 2003-2004. DCWASA was required to provide notification to customers whose lead service lines had incorrectly passed due to using the incorrect methodology. DCWASA shall (Docket No. SDWA-03-2005-0025DS).

Summary of Sanitary Surveys

1995 Sanitary Survey of the Drinking Water Distribution System of the District of Columbia

The 1995 survey was conducted from April to June. The survey objectives were to identify the problems associated with bacteriological activity in the District of Columbia (DC) system and provide recommendations to alleviate those problems. The survey included both the storage facilities and the distribution system operated and maintained by WASUA and the WA Division of the U.S. Army Corp. of Engineers. Laboratory data for 1993 through 1995 indicated elevated bacteriological activity in service reservoirs and the DCWASA distribution system. The distribution system reservoirs had not been drained and inspected in approximately 20 years, and on-site inspections of the reservoirs revealed numerous sanitary deficiencies. Survey findings included 185 recommendations that addressed treatment practices, cross connections, distribution system O&M practices, consecutive systems, and operating procedures. Ninety one recommendations were developed for reservoir facilities and operating conditions.

1996 Follow-Up Sanitary Survey of the Drinking Water Distribution System of the District of Columbia

The 1996 survey was conducted during the month of September. Since the 1995 Sanitary Survey Report was completed, the DC formed a new Regional Water and Sewer Authority (WASA) to oversee operations of its water and sewer systems. Of the 185 recommendations in the 1995 survey, 23 were fully completed, and 129 were under contract or part of a future plan. Seven storage tanks were drained, cleaned, and inspected. An improved flushing program was initiated. SOPs consistent with AWWA standards for water main disinfection practices were developed. Numerous other engineering projects were underway, such as a reservoir inspection program, design of reservoir improvements, clearwell improvements, development of O&M manuals, creation of a hydraulic model to evaluate system pressures, and plant process control improvements.

1998 Follow-Up Sanitary Survey of the Drinking Water Distribution System of the District of Columbia

A follow-up survey was conducted from July through September of 1998. Of the 185 recommendations identified during the 1995 Sanitary Survey, 77 were completed, and 31 had not been addressed. For 15 of the 31 recommendations that were not addressed, some form of corrective action had been taken, but this had failed to eliminate the sanitary risk. The remaining 77 recommendations were under contract, planned for a future contract, under consideration, or part of a long term plan. Findings from the 1998 Sanitary Survey related to water quality monitoring included:

- No coliform violations were observed between the summer of 1996 and the 1998 follow-up survey
- The TCR sampling plan and sampling sites were approved as more representative of distribution system water quality.

In terms of operations and maintenance, the 1998 survey found that WA and DCWASA continued to make significant progress in distribution system rehabilitation work, which included clearwell improvements; corrosion control evaluations; finished water reservoir cleaning, inspection, improvements and operating procedures; development of flushing program, and reduction in cross connection hazards. Training was provided to utility staff on flushing, pipe and valve repair, water main disinfection, backflow prevention and cross-connection control. Additional training recommended in the 1998 survey included:

- Use of new O&M manuals and SOPs during training sessions,
- Development of a written training program for coliform sampling,
- Training for storage tank O&M, and
- Training of new staff (e.g. flushing crews, inspectors).

1999 Sanitary Survey and Review of Turbidity Risk of the Washington Aqueduct

The 1999 sanitary survey of facilities owned by Washington Aqueduct (WA), conducted during February and March, documented 73 potential sanitary risks. The major water quality improvements that were identified as necessary to address the sanitary deficiencies are summarized below. (Note: the responses in parentheses indicate whether the deficiency had been addressed at the time of the 2003 survey.)

- Need comprehensive watershed protection program for Dalecarlia Reservoir (no).
- Develop and implement a comprehensive cross connection control program (no).
- Update SOPs for WTP process operations and train operators on current procedures (no).
- Include coagulant aid and filter aid polymers in jar testing (yes).
- Remove dead eels from open well at gatehouse at McMillan Reservoir (yes).
- Initiate treatment plant valve exercising program (partially meets, all valves not included in program).
- Reduce amount of backlogged maintenance tasks with more focus on prioritizing (partially meets, current process does not include prioritization).
- Clean out WTP sedimentation basins on regular schedule (yes).

2002 Follow-Up Sanitary Survey of the Drinking Water Distribution System of the District of Columbia

The 2002 survey was conducted from June through August. Of a total of 193 recommendations identified during the 2002 survey, 8 were new recommendations, and 92 had been completed. Twelve recommendations had been re-opened, primarily because facility O&M manuals had not been used to train operations staff. At the time of the survey, the following observations were made:

- Since the original sanitary survey in 1995, all water storage facilities have been cleaned and inspected and most have been completely rehabilitated. The two remaining storage facilities that require major maintenance are under contract.
- In May of 1999, the Water Quality Division established a 16-person flushing team to conduct unidirectional flushing of the entire distribution system every 2 years. Recommendations related to the flushing program included modifications to address problem areas, hydrant operating procedures, pressure monitoring, establishment of programs to address dead-ends and blow-offs.
- WA made no progress on a cross-connection control program. DCWASA established a cross-connection control program, but staff shortages limited program implementation.

- Since chloramination began in November 2000, an increase in total coliform positives was observed each year.
- Staff training is needed on storage tank O&M, facility O&M manuals, on-site inspections, and distribution system operator certification.
- Total coliform sampling sites should be reevaluated to assure they represent distribution system conditions and are not influenced by biofilms present in building plumbing.
- There is a need for an integrated database that could store all data and process information related to water quality and system operations.

October 17, 2003 Sanitary Survey of the Washington Aqueduct Draft Report
A sanitary survey of the facilities owned by WA (including intake works on the Potomac River, transmission mains, two WTPs, and pumping stations) was conducted for USEPA Region 3 by the Cadmus Group. Finished water storage and the distribution system were not included in the scope of this survey. The sanitary survey team also conducted an optimization evaluation of the two WTPs based on turbidity data from July 2002 to June 2003. Of 37 sanitary deficiencies identified, the 9 highest priorities included:

- Develop and implement a comprehensive cross connection control program, including procedures for tagging and inspecting devices.
- Establish an optimization program for each WTP, including detailed filter evaluations.
- Update SOPs for WTP process operations and train staff on current procedures.
- Install an automatic switchover system for the chlorine feed system at the Dalecarlia WTP.
- Formalize new solids handling plan for Dalecarlia WTP and incorporate it into SOPs.
- Always add PAC1 as a primary coagulant at McMillan WTP due to the presence of two open reservoirs between the alum addition point and the treatment plant.
- Move sampling ports for turbidimeters on individual filters so they monitor total filter effluent.
- Develop procedures to minimize hydraulic changes in filter operations during backwash.
- Properly seal clearwell openings to reduce the chance of material entry. Improve clearwell vent termination points to minimize vandalism and animal entry (screening).

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Supplement to History and Evaluation of Lead Monitoring Program

USEPA Region 3 provided HDR/EES with laboratory sample reports, 90th percentile calculations and correspondence related to Lead and Copper Rule (LCR) monitoring, including first draw and second draw samples. HDR/EES reviewed 90th percentile calculations prepared by DCWASA and checked them against original laboratory reports. The results of this analysis are discussed in the main body of the report. This appendix lists numbers of LCR monitoring sites that exceeded the action level in each monitoring period. Separate tables are provided for first draw samples (Table 1) and second draw samples (Table 2).

First Draw Lead Results

Table 1 shows the number of DCWASA sample sites where lead concentrations were measured at levels higher than 15 µg/L and how many of those sites exceeded the Action Level in two or more LCR monitoring periods.

Table 1 First Draw Lead Samples -
Listing of Sample Sites Where Lead Levels Were > 15 µg/L

Monitoring Period	Number of Sample Sites Exceeding Action Level of 15 µg/L	Number of Sample Sites Exceeding Action Level in Two or More LCR Monitoring Periods
January – June 1992	16	10
July – December 1992	28	15
January – June 1993	5	4
July – December 1993	23	15
January – June 1994	9	7
July – December 1994	8	7
January – June 1997	5	3
July – December 1997	5	3
July – December 1998	4	3
January – June 1999	3	1
July-Sept. 1999	3	2
July 2000 – June 2001	4	4
Revised July 2000-June 2001 by USEPA Region 3	9	9
July 2001 – June 2002	26	22
January – June 2003	30	20
July – December 2003	35	28
January – June 2004	73	30
July – December 2004	40	24

Second Draw Lead Results

Table 2 lists the addresses for sample sites where lead concentrations of second draw samples were measured at levels higher than 15 µg/L and how many of those sites exceeded the Action Level in two or more LCR monitoring periods.

Table 2 Second Draw Lead Samples -
Listing of Sample Sites Where Lead Levels Were > 15 µg/L

Monitoring Period	Number of Sample Sites Exceeding Action Level of 15 µg/L	Number of Sample Sites Exceeding Action Level in Two or More LCR Monitoring Periods
January – June 1997	4	2
July-Dec. 1997	4	4
July-Dec. 1998	3	2
January – June 1999	3	1
July-Sept. 1999	5	4
July 2000 – June 2001	3	3
July 2000 – June 2001 (revised by USEPA Region 3)	9	9
July 2001-June 2002	24	24
January – June 2003	17	15
July-Dec. 2003	29	26
January – June 2004	63	25
July-Dec. 2004	35	21

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Summary of Corrosion Control Studies

June 1994 Corrosion Control Study (ECG, Inc.)

The purpose of this corrosion control study was to determine the most effective treatment approach to control lead and copper corrosion in drinking water supply lines. The study included a desktop study, a screening evaluation of corrosion inhibitors using jar testing, and full-scale pipe loop experiments. Technical and cost constraints were identified for specific corrosion control treatment alternatives. The desktop study found that optimizing the pH and alkalinity was intrinsically related to the calcium hardness adjustment and calcium carbonate precipitation potential. The results of the screening evaluation showed that zinc orthophosphate demonstrated lower dissolved lead concentrations in the static system than the silicates, polyphosphates or straight orthophosphate. Both the silicates and the polyphosphates actually showed elevated dissolved lead concentrations when compared with the control conditions.

Three pipe loop models were constructed to test finished water at the Dalecarlia water treatment plant. One model was used to test a zinc orthophosphate (1:5 ratio); a second model was used to test a pH/alkalinity/calcium hardness adjustment, and a third model served as a control (no corrosion control inhibitor or water quality adjustment implemented). These pipe loops were monitored for lead and copper concentrations in standing and flowing water samples, as well as for direct metal corrosion from coupons and inserts over a 10-month study period. The second pipe loop (pH/alkalinity/calcium hardness adjustment alternative) had severe calcium carbonate deposition problems. Zinc orthophosphate showed lower corrosion rates and reduced lead concentrations in the water in 84% of days studied; however, the use of zinc orthophosphate system-wide must be questioned due to discrete samples with elevated lead concentrations, overall costs, and downstream treatment of phosphorous and zinc.

The study concluded that WA water treatment plants should optimize current practices by maintaining a consistent pH level, which would optimize the Langelier Saturation Index in the positive range, as close to zero as possible. Further, it was recommended that WA calculate Calcium Carbonate Precipitation Potential (CCPP) in the distribution system on a daily basis after treatment with the goal of keeping the CCPP at or near 0; (the study determined that it was not feasible to obtain CCPP levels between 4 and 10). The study noted that further research was needed to study the optimal balance of corrosion control, scaling and trihalomethane formation potential.

Dec. 1996 Expert Review (Jonathon Clement)

An expert review, commissioned by USEPA, was conducted to review the June 1994 corrosion control study and supplemental system information, including a sanitary survey, pipe material information and water quality data for the period of September 1995 to August 1996 (pH, alkalinity, chlorine, and calcium). The selection of corrosion control strategy was driven by the high percentage of unlined cast iron pipe in the DCWASA system (approximately 73% of total miles of main). Comments were based primarily on the supplementary information. Two viable treatment strategies for lead control included: (1) stabilize and increase the pH to 9.0, and (2) maintain the pH between 7.4 and 7.8 and add orthophosphate. The use of orthophosphate was not recommended unless site-specific testing was conducted with unlined cast-iron pipe loops, constructed with DCWASA distribution system mains, to determine the effects of orthophosphate on iron release and red water. The alternative of pH adjustment to 9.0 appeared to be more appropriate; however, potential issues with calcium precipitation, THM formation potential and water disposal issues (higher pH) required further evaluation. Additionally, the recommendations indicated that, regardless of treatment selection, maintaining a consistent distribution system pH should be addressed. The study recommended avoiding pH variations of more than 0.5 pH units.

Jan. 1998 Caustic Soda Feasibility Study (Malcolm Pirnie)

This feasibility study, conducted for the Washington Aqueduct, addressed Conditions 1a and 1b of the conditional designation of Optimum Corrosion Control Treatment, dated July 16, 1996. This condition required WA and DCWASA to determine the feasibility of switching from lime to sodium hydroxide to control pH. The feasibility assessment included: (part 1a) a determination of the highest pH that could be maintained using sodium hydroxide without causing exceedance of the total trihalomethane MCLs and excessive precipitation of calcium carbonate in the distribution system, and (part 1b) estimation of construction costs and annual O&M costs for the sodium hydroxide feed system. A spreadsheet model was used to estimate the maximum pH that could be maintained using lime or caustic soda while preventing excessive precipitation of calcium carbonate. The modeling results indicated that excessive calcium carbonate precipitation using caustic soda would begin at pH 0.2 units higher than when using lime. Additionally, modeling results indicated that excessive precipitation would occur if a pH of 8.5 was maintained throughout the year for either lime or caustic soda. Caustic soda would provide some benefits in terms of process control and maintenance requirements. Disinfection by-product levels were estimated to be the same whether caustic soda or lime was used. The chemical cost of caustic soda was approximately 6.5 times higher than lime for a desired target finished water pH of 7.4, and was approximately 5.0 times higher than lime for a desired target finished water pH of 8.5. The capital cost of the caustic soda feed system was estimated at $720,000 (1997 dollars).

May 1998 Corrosion Inhibitor Study for Dalecarlia and McMillan Water Treatment Plants (Malcolm Pirnie)

The corrosion inhibitor study, conducted for the Washington Aqueduct, included three primary tasks: (1) determine the approximate corrosion inhibitor dosage rate; (2) estimate phosphate levels in wastewater; and (3) estimate capital and O&M costs for the corrosion inhibitor feed system. The consultant also reviewed the current literature and immersion tests conducted by ECG Inc. to compare the relative benefits of zinc orthophosphate and orthophosphate (phosphoric acid). The study concluded:

1. Zinc orthophosphate does not provide any long-term benefits over orthophosphate in controlling lead levels in the water.
2. The chemical costs for zinc orthophosphate are approximately twice the chemical costs for orthophosphate.
3. If WA decides to use corrosion inhibitors as a lead control strategy, orthophosphate should be used at a dosage rate of 1.0 mg/L as PO_4.
4. Assuming a phosphate dose of 1.0 mg/L as PO_4, the maximum phosphate concentration to reach the wastewater treatment plant would be approximately 1.0 mg/L as PO_4, which would result in a 10% increase in phosphorous levels at the wastewater treatment plant under the worst case scenario.
5. The total estimated capital costs for an orthophosphate feed system are $350,000 and $220,000 for the Dalecarlia and McMillan plants, respectively.

6. The annual O&M costs of orthophosphate are $166,000 and $148,000 for the Dalecarlia and McMillan plants, respectively. The annual cost savings due to reduction in lime usage is approximately $30,000 for each plant.

Oct. 2003 Expert Review – Draft Report (Marc Edwards)

This expert review, conducted for USEPA Region 3, was based on an extensive literature review and a few experiments. The report found no reasons for DCWASA to ~~not~~ implement phosphate addition for corrosion control but recommended that additional studies and corrective actions should be conducted to further diagnose the DCWASA lead problem. The report also indicated that it could not be determined whether phosphate addition would address the lead problem. The following prioritized action items were recommended for mitigating the lead problem:

a. Compare LCR sampling protocols for the seven utilities treating Potomac River water, and compare samples for the old and new sampling protocols. Determine if the new sampling protocol mobilizes more particulate lead. Check use of filtration devices on kitchen taps at LCR sampling sites, and document sampling procedures used at these sites.
b. Initiate a corrosion study of brass, pure lead and lead-solder coupled to copper to evaluate galvanic corrosion, chloramine corrosion and the combined effect of nitrate and chloramine on each lead-bearing material.
c. Conduct a filtration analysis of solids present in the DCWASA system and try to determine their source.
d. Conduct a study or review existing data, if available, on nitrification events in the DCWASA system and sister systems served by the Dalecarlia water treatment plant.
e. Examine historical data on lead, copper and zinc loading to the sewage treatment plant from the DCWASA system, before and after chloramine disinfection was initiated (November 2000).
f. Examine whether DCWASA's practice of switching disinfectants each Spring (from chloramine to free chlorine) adversely affects corrosion control.

Spring 2004 USEPA Region 3 /DCWASA Response to Edwards' Recommendations

This paper was developed to provide background information for DC city council and congressional hearings during 2004. This response included the following information with respect to the Expert Review from 2003:

- DCWASA has initiated a plan to study corrosion rates of brass, pure lead and lead solder before and after corrosion control treatment.
- DCWASA has collected filtrate samples and will have them analyzed per recommendation.
- DCWASA has conducted monitoring for parameters that would indicate the occurrence of nitrification. The sampling effort has not found evidence of nitrification in the system.
- A review of wastewater treatment plant data has indicated that no significant increase in lead, copper, or zinc levels occurred after conversion to chloramine.

April 2004 Desktop Corrosion Control Study (CH2MHill)

This study reviewed water quality changes in WA customers' distribution systems and engineering reports on corrosion control and LCR compliance strategies. Corrosion control options that are evaluated included: (1) maintaining a constant, high pH at the two water treatment plants using either quicklime (current practice) and/or sodium hydroxide, and (2) feeding a corrosion inhibitor such as orthophosphate while maintaining a constant pH of about 7.7 throughout the year.

Mathematical modeling conducted for this study found that adjustment of finished water pH to 8.5 resulted in severely elevated levels of calcium carbonate precipitation potential, indicating that excessive calcium precipitation would occur. The report concluded that pH adjustment to pH 8.8 year-round is not advisable for the Washington Aqueduct.

The report concluded that orthophosphate appears to be the "reoptimized" best treatment for Washington Aqueduct. However, further testing was recommended using partial system application of phosphoric acid. The report also recommended that the Washington Aqueduct conduct pilot-scale testing using pipe loops of DCWASA lead service lines to help determine optimal corrosion inhibitor feed rates. The Optimum Corrosion Control Treatment document was prepared and submitted to USEPA for approval.

July 2004 Evaluation of Orthophosphate Addition Effects on Microbial Water Quality (Anne Camper)

The purpose of this technical memo was to address four specific questions posed by Cadmus. The four questions and answers are summarized below.

1. ***Considering DCWASA's distribution system infrastructure and water quality, do you believe that orthophosphate addition will help control biofilm growth? More specifically, how will the addition of orthophosphate affect TCR compliance?*** It is probable that phosphate addition will have a beneficial effect on regrowth in the DCWASA system in the long term. In the short term, there may be some elevated bacterial counts. In areas of the distribution system that were not flushed prior to phosphate addition, increased bacterial counts are probable.

2. ***What detrimental effects could there be in a distribution system such as DCWASA's from maintaining an orthophosphate residual of 3 mg/L?*** The only potential effect on microbial growth/biofilms would be the rate at which surfaces are impacted by the corrosion inhibitor and the time required to reach equilibrium.

3. ***Can the Aqueduct reduce the disinfectant residual concentration in the DCWASA distribution system without adversely impacting TCR compliance?*** If corrosion control has a positive impact on microbial counts, it is possible that the chloramines dose can be reduced, as long as dead ends and low flow areas continue to have a measurable residual.

4. ***DCWASA practices unidirectional flushing in their distribution system and routinely flushes the entire system approximately every two years. How important is unidirectional flushing for the DC distribution system? In your opinion, how often should WASA flush their entire system****?* Flushing should be considered as part of DC's program to improve microbial water quality. Because of the predominance of unlined cast iron pipes in the DC system, flushing is critical for maintaining water quality, particularly in low flow areas where loose deposits accumulate. It is difficult to determine flushing frequency as it depends on many factors including water quality, cost, historical flushing practices, personnel resources, water availability during drought conditions, and disposal of flushing water.

Nov. 2004 pH Study Report for Washington Aqueduct (CH2M Hill)

The purpose of this report was to evaluate alternatives and recommend process changes for achieving optimized pH control at the Dalecarlia and McMillan water treatment plants. Four alternatives were evaluated: (1) optimize existing pH control equipment; (2) replace existing lime slakers with batch-type slaker systems; (3) trim final pH with caustic while continuing to use lime for base load pH adjustment; and (4) replace lime feed with caustic feed. Recommendations were based on the third alternative: trim final pH with caustic and use lime for base pH adjustment. The report recommended that the existing lime feeders be replaced with properly sized feeders to improve control of lime feed.

Effects of External Currents and Dissimilar Metal Contact on Corrosion and Metals Release From Lead Service Lines (HDR and Cadmus)
The purpose of this project was to use laboratory-scale testing rigs to identify whether grounding and/or galvanic currents can have a significant and prolonged impact on metals release from lead service lines and leaded-brass appurtenances. Different forms of grounding currents (AC vs. rectified) were impressed on both scaled and un-scaled lead service lines used in the testing rigs. Galvanic currents were generated using the coupling of different lengths of copper tubing to the lead service lines while the surface potential was measured. The testing was not intended to replicate distribution system conditions but to evaluate various scenarios that generate the highest possible metal release and the greatest lead service line surface effects. The draft final report on this project was issued in November 2005.

Technical Support on Nitrification Inhibition From Zinc (Virginia Military Institute and Cadmus)
This project was a preliminary step towards assessing the potential impacts of zinc-phosphate, a proposed corrosion control chemical for drinking water, on the operation of the Arlington County (VA) wastewater treatment plant. More specifically, this project evaluated the concentration of zinc that could be tolerated by the biological nitrogen removal processes at the wastewater treatment plant. The findings of this project will help determine whether or not zinc at the proposed zinc orthophosphate dose would have an adverse impact on biological nutrient removal processes at the Arlington plant. The project consists of bench scale studies as well as a brief literature review. The estimated final report on this project was issued in September 2005.

Characterization of Natural Organic Matter in DC Drinking Water (Univ. Washington and Cadmus)
The purpose of this project was to characterize the properties and reactivity of NOM, including seasonal variations, in the raw and treated water to improve understanding of DBP formation, the effectiveness of existing treatment on NOM removal, and the role of NOM in metal solubility. Project activities include sample collection and laboratory-scale studies. The final report on this project was issued in May 2006.

(On-going) Proposed Flow-Through, Lead Pipe Loop Test Plan (CH2MHill)
The primary purpose of the pipe loop testing at the Washington Aqueduct is to evaluate the effectiveness of alternate corrosion control strategies on reducing lead concentrations in DC drinking water. A comparison of the effectiveness of two alternate corrosion inhibitors (phosphoric acid and zinc orthophosphate) will be conducted. Finished water produced at the WA's Dalecarlia WTP will be used as the source water for the testing. Samples of lead service lines excavated from the DCWASA system will be used to construct the proposed pipe loops.

(On-going) Evaluation of Potential Mechanisms of Lead Release Related to Conversion from Free Chlorine to Chloramines and Evaluation of Scale from Lead Service Line Specimens Excavated from the DCWASA System.

The USEPA has evaluated the potential mechanism of lead release in the DCWASA system by conducting theoretical evaluations and laboratory studies related to the solubility of potential lead solids that may be present in the system based on water quality conditions and by evaluating the scale components from several lead service line specimens excavated from DCWASA's distribution system. Results of these evaluations have been presented at the AWWA Water Quality Technology Conferences in 2001 and 2004 (Schock, 2001; Schock and Giani, 2004) and in a presentation to the Virginia Section of AWWA in April 2005 (Schock, 2005) and are summarized here. These presentations indicate that a mechanism potentially responsible for the change in lead levels with the conversion from free chlorine to chloramines relates to the solubility of Pb (II) vs. Pb (IV) pipe scales. Control of lead in drinking water has generally been presumed to be controlled by Pb (II) solids that form on lead containing materials. Pb (IV) has a lower theoretical solubility than Pb (II) carbonate solids, and its presence may result in relatively low lead levels. USEPA has evaluated the theoretical formation of Pb (IV) compounds, which can form under relatively high oxidation-reduction (ORP) potentials, and the lower ORP of chloraminated water when compared to water with free chlorine (Schock, 2001; Schock and Giani, 2004; Schock, 2005).

By switching to chloramines, the ORP of the DCWASA water may have been lowered, causing Pb (IV) solids to convert to more soluble Pb (II) solids and resulting in release of lead and higher lead levels measured at the tap. This mechanism, along with supporting theoretical, laboratory, and field water quality and scale analysis data are summarized in these papers and presentations, including evidence of the presence of Pb (IV) solids in lead service line pipes excavated from the DCWASA system prior to the switch to chloramines. These LSL specimens primarily contained Pb (IV) compounds (plattnerite and scrutinyite) with only traces of Pb (II) compounds (cerrusite and hydrocerrusite). In addition, lead levels, measured in residential homes in the DCWASA system, decreased during a one-month switch to free chlorine in April of 2004 when compared to lead levels from the same sites during chloramination. The USEPA is continuing with these investigations.

Environomics Contract 68-C-02-042
Work Assignment WA 4-13

Final Report

Summary of Lead Service Line Replacement Program

From 2002 - 2005, DCWASA was required to replace 7% of the lead service lines in the system each year due to exceedances of the lead action level.

Sept. 2003 Report on the Materials Evaluation and Initial Inventory

In September 2003, DCWASA updated its inventory of lead service lines and estimated that of the system's 120,000 service connections, 23,071 were lead service lines (count as of September 30, 2003).

Inventory of Lead Service Lines (2004 map)

DCWASA developed a map at a scale of 1:16,000 that shows the approximate locations of lead service lines in the distribution system, based on the initial inventory conducted in 2003. Of the estimated 23,071 lead service lines in the system, the map presents those that could be geocoded. In Task 6, this map will be reviewed as part of an evaluation of lead levels in the system.

2003 Sampling Results of Lead Service Lines (2004 map)

DCWASA developed a map in 2004 at a scale of 1:16,000 that shows lead sampling results for lead service lines. The map delineates sample results less than or equal to 15 ppb, sample results between 15 ppb and 300 ppb, and sample results greater than or equal to 300 ppb. In Task 6, this map will be used, along with distribution system water quality data, to determine if there is a statistically significant correlation between elevated lead levels and other water quality parameters, such as pH, for different geographical areas.

Oct. 24, 2003 Annual Report of DCWASA's Lead Service Line Replacement Program

On October 24, 2003, DCWASA reported that during the period October 1, 2002 to September 30, 2003 it had replaced 385 lead service lines through physical replacement including 79 "full" replacements and 306 "partial" replacements. A "partial" replacement means that something other than the entire length of the service line is replaced (Code of Federal Regulations, Title 40, § 141.84(d)). Title 40 CFR §141.84 requires that a public water system replace the portion of the lead service line owned by the system, but does not require that the system bear the cost of replacing portions of the line that the system does not own.

2003-2004 Replacement of Lead Service Lines (2004 map)

DCWASA developed a map at a scale of 1:16,000 that shows both completed lead service line replacements and those planned to be replaced in 2004. This map shows that 524 replacements had been completed and 817 were scheduled for 2004.

Oct. 8, 2004 Annual Report DCWASA's Lead Service Replacement Program

DCWASA reported that it had replaced 1,793 lead service lines between October 1, 2003 and September 30, 2004.

Summary of Correspondence on Designation of Optimal Corrosion Control Treatment

July 16, 1997

USEPA Region 3 conditionally designated Optimized Corrosion Control Treatment (OCCT) as maintenance of a slightly positive Langelier Saturation Index through pH adjustment. As a condition of this designation, USEPA Region 3 issued an Administrative Order (AO) for WA and DCWASA to jointly assess the feasibility of alternate corrosion control treatment including use of sodium hydroxide for pH control, and use of a non-zinc orthophosphate corrosion inhibitor. USEPA Region 3 set a deadline of September 15, 1997 for completing the assessment.

August 15, 1997

DCWASA responded to USEPA Region 3's July 16, 1997 letter outlining plans for WA to conduct studies on corrosion control treatment and DCWASA to conduct studies on the effects of these treatments on wastewater plants. WA will conduct studies on sodium hydroxide including estimation of construction costs and O&M costs for a sodium hydroxide and phosphate feed systems. The letter acknowledges the Sept. 15, 1997 deadline for these studies.

September 4, 1997

WA responded to USEPA Region 3's July 16, 1997 letter outlining the same proposed and on-going studies outlined by DCWASA in their Aug. 15, 1997 letter. WA revised the estimated schedule for completing these studies to be November 1, 1997 for the caustic soda studies and March 1998 for the phosphate studies.

February 29, 2000

USEPA Region 3 designated the use of pH adjustment as the OCCT for the WA distribution systems which required the WA to maintain the highest pH level attainable at the entry points to the distribution system without causing excessive calcium carbonate precipitation in the distribution system. USEPA also designated that a minimum pH of 7.7 be maintained at the entry points to the distribution system and at all tap samples within the distribution system. USEPA Region 3 also reduced the requirement for LCR tap monitoring to once per year at 50 sites.

May 1, 2000

In response to USEPA Region 3's Feb. 29th letter, DCWASA proposed modifications to the Optimal Water Quality Parameters. The proposed modifications were developed jointly by WA, DCWASA and USEPA Region 3. Specifically, the proposed modifications would allow the minimum finished water pH requirement to change monthly to account for seasonal changes in untreated water quality as follows: January (7.7), February (7.8), March (7.7), April (7.6), May (7.5), June (7.4), July (7.4), August (7.4), September (7.4), October (7.5), November (7.5), and December (7.6). Also, the minimum pH at distribution system sites would change from 7.7 to 7.0, and would be measured at 12 sites vs. 10 sites proposed by USEPA Region 3.

May 3, 2000
In response to USEPA Region 3's Feb. 29th letter, WA proposed modifications as outlined in DCWASA's May 1st letter. One additional suggestion was that the proposed Optimal Water Quality Parameters be made effective for the 6 month monitoring period beginning July 1, 2000.

May 17, 2002
USEPA Region 3 revised its designation of OWQP with respect to the minimum monthly entry point pH requirements per proposed levels requested by DCWASA and WA in May 2000, noting that the decision had been verbally agreed between WA and USEPA Region 3 in 2000. The decision was made effective from the LCR monitoring period which began on July 1, 2000, The OWQP for the distribution system tap samples was changed to a minimum pH of 7.0.

April 30, 2004
USEPA Region 3 designated use of zinc orthophosphate for partial system application in the 4th High Pressure Zone.

May 28, 2004
USEPA Region 3 modified its April 30, 2004 designation of OCCT for the DC distribution system to use orthophosphate instead of zinc orthophosphate for the 4th High Pressure Zone.

Aug. 3, 2004
USEPA Region 3 modified the interim designation of OCCT for the DCWASA distribution system to consist of application of orthophosphate subject to stated conditions and water quality parameters (source: correspondence from USEPA Region 3 to WA and DCWASA 8/3/04). Specifically, USEPA Region 3 has stipulated that the WA will meet a pH goal of 7.8 +/-0.1 (7.7+/-0.1 per later revisions August 20, 2004 and September 7, 2004) for finished water leaving both water treatment plants, and 7.7 +/-0.1 for water samples from the distribution system during the passivation period.

LEAD PROFILES

Profile No.	Date of profile	Profile Quadrant	Special Profile Conditions
Profiles Collected during Chloramination			
1	12/8/2003	NW	
2	12/15/2003	NW	
3	1/5/2004	NW	
4	1/13/2004	NW	Repeat of Profile 1 following partial LSL replacement
5	2/9/2004	NE	
6	2/24/2004	NW	Repeat of Profile 3 following partial LSL replacement
7	3/2/2004	NW	
8	3/9/2004	NW	
9	3/16/2004	NW	
10	3/24/2004	NW	
11	3/24/2004	SE	
12	3/30/2004	NW	
13	3/31/2004	NW	
14	4/1/2004	NW	
Profiles Collected during Temporary Switch to Alternative Disinfectant (free chlorine)			
15	4/5/2004	NW	Affected by switch
16	4/6/2004	NW	Affected by switch
17	4/6/2004	NW	Affected by switch
18	4/13/2004	NW	Affected by switch

Profile No.	Date of profile	Profile Quadrant	Special Profile Conditions
19	4/26/2004	NW	Second repeat of Profile 3 following partial LSL replacement; Affected by switch
20	4/27/2004	SE	Repeat of Profile 11; Affected by switch
21	4/29/2004	NW	Second repeat of Profile 1 following partial LSL replacement; Affected by switch
22	4/30/2004	NW	Repeat of Profile 12; Affected by switch
23	5/3/2004	NW	Repeat of Profile 10; Affected by switch
24	5/3/2004	NW	Repeat of Profile 14; Affected by switch
25	5/7/2004	NW	Repeat of Profile 13; Affected by switch
Profiles Collected during Chloramination, after Temporary Switch to Alternate Disinfectant (free chlorine)			
26	5/18/2004	NE	Repeat of Profile 5; Affected by switch
27	6/28/2004	NW	Second Repeat of Profile 14
28	7/6/2004	NW	
Profiles Collected after Orthophosphate Addition			
29	7/16/2004	NW	Second Repeat of Profile 13
30	11/30/2004	NW	
31	12/6/2004	NW	
32	1/6/2005	NW	Second Repeat of Profile 10
33	1/25/2005	NW	
34	2/22/2005	NW	

Profile No.	Date of profile	Profile Quadrant	Special Profile Conditions
35	3/30/2005	NW	
36	4/29/2005	NW	
37	5/16/2005	NW	
38	6/1/2005	NW	
39	6/7/2005	NW	
40	7/25/2005	NW	
41	9/28/2005	NW	
42	10/5/2005	NE	
43	11/29/2005	NW	
44	12/12/2005	N	
45	1/27/2006	NE	

(Notes on Profile Graphs to follow:

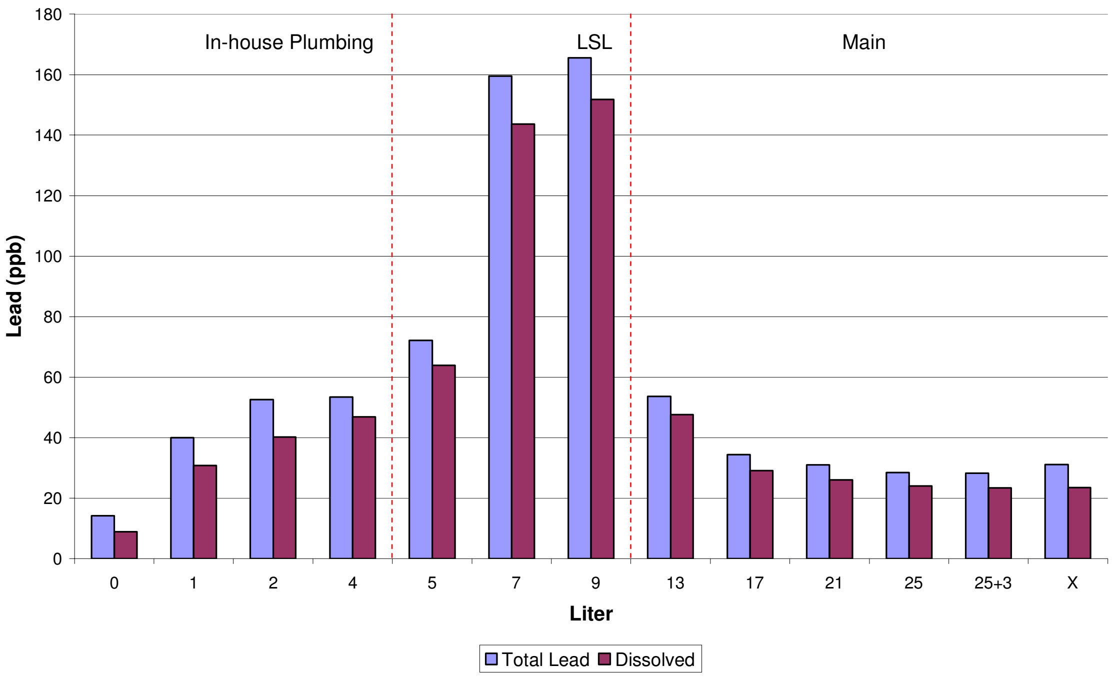
1. Flowing samples designated ‘0’ or ‘00’ and samples collected that were representative of the water main may have measurable lead due to rapid release of lead from the lead service line to the water as it flowed through the service piping, and/or back siphonage of water from branches of premise piping.

2. Samples designated “X” reflect water hammer conditions

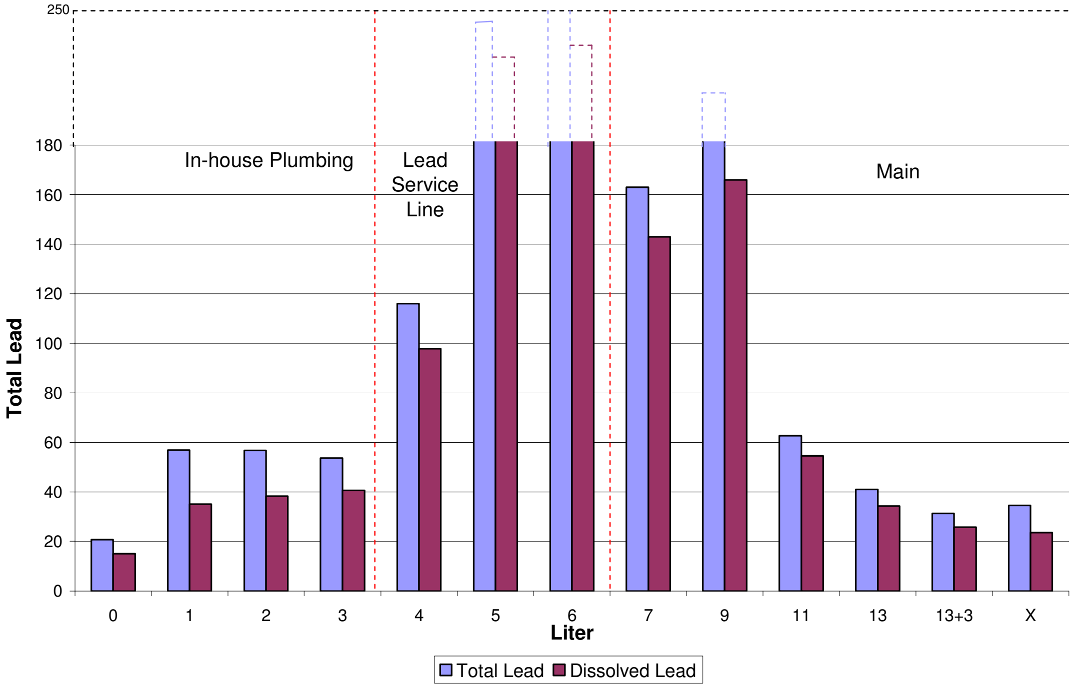
3. Samples designated “25+3” for example; indicate samples collected after allowing the water to flow for 3 minutes after the 25th liter stagnation sample was collected.

I. Profiles Collected during Chloramination

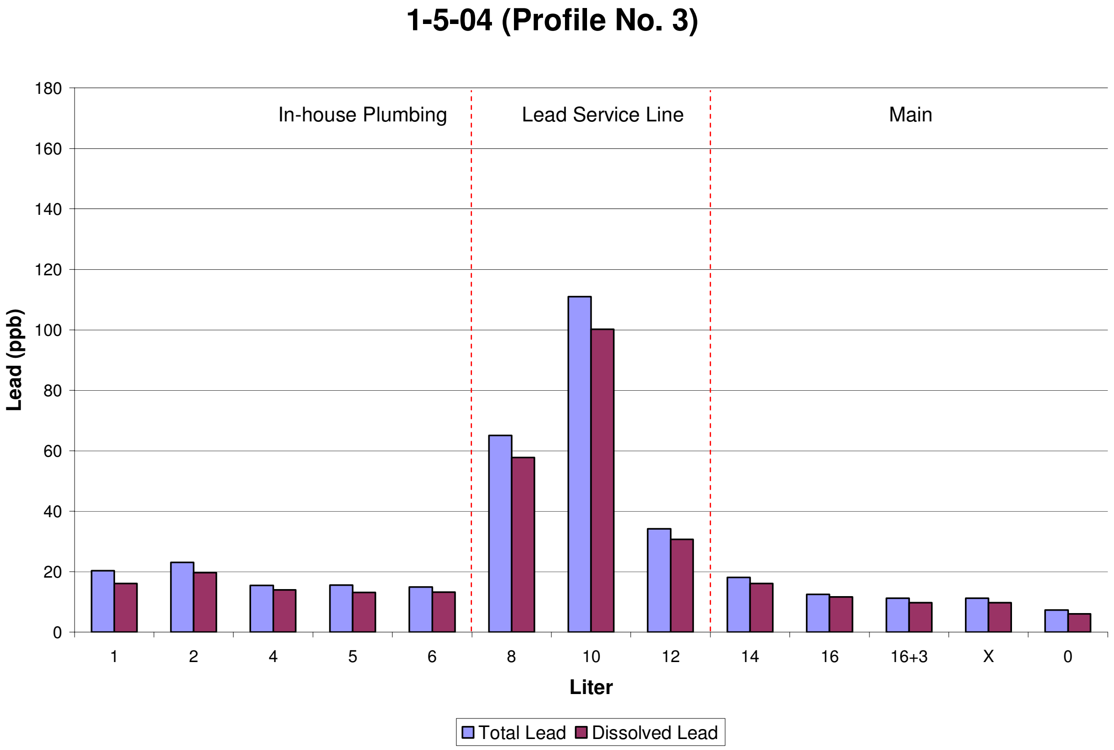
12-08-03 (Profile No. 1)



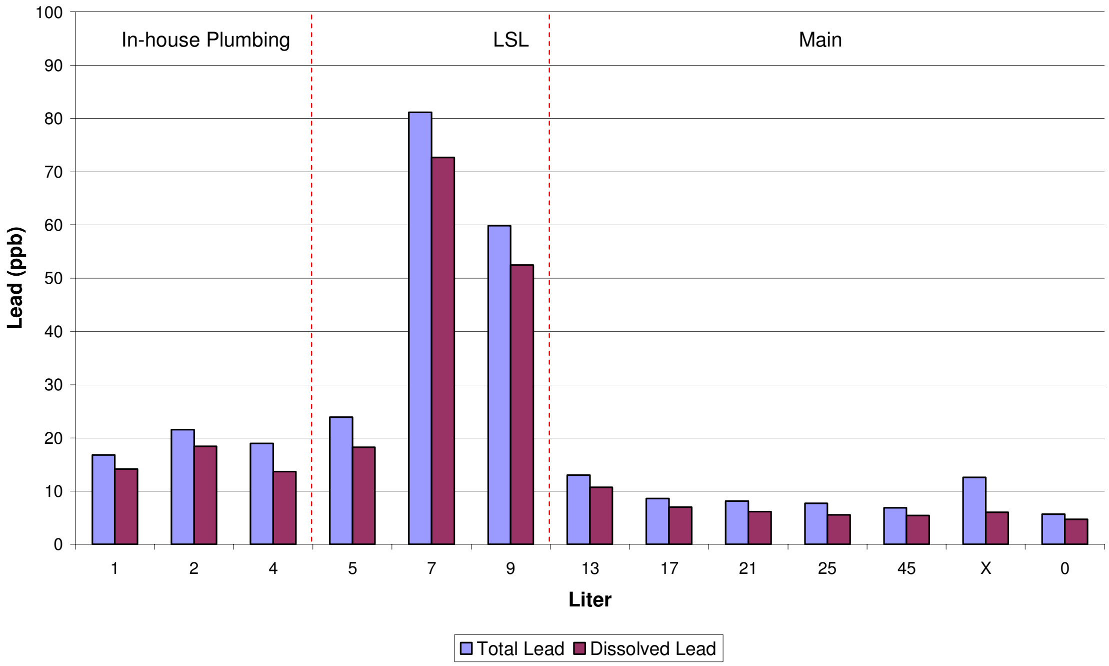
12-15-03 (Profile No. 2)



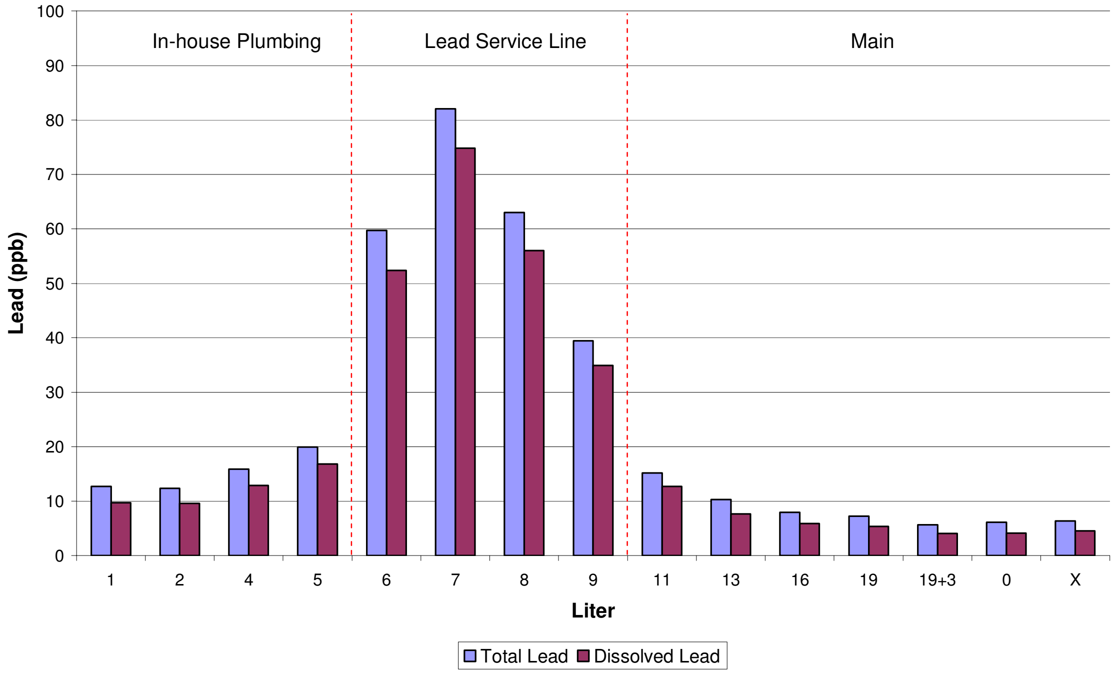
* Footnote to Profiles: Flowing samples designated ‘0’ or ‘00’ and samples collected that were representative of the water main may have measurable lead due to rapid release of lead from the lead service line to the water as it flowed through the service piping, and/or back siphonage of water from branches of premise piping.



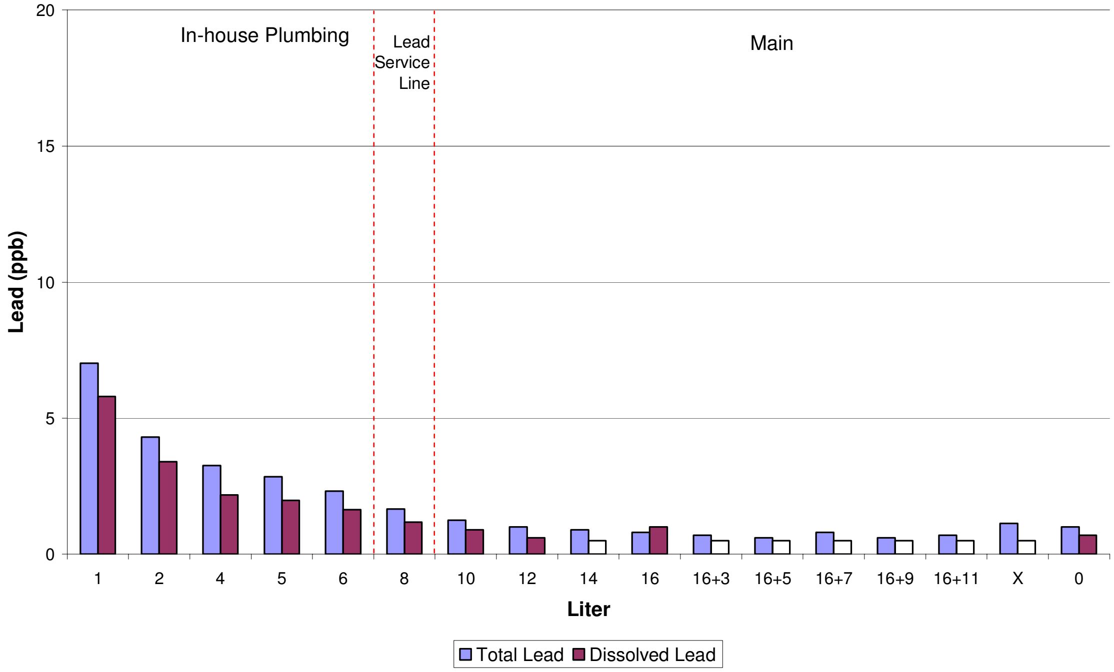
1-13-04 (Profile No. 4)



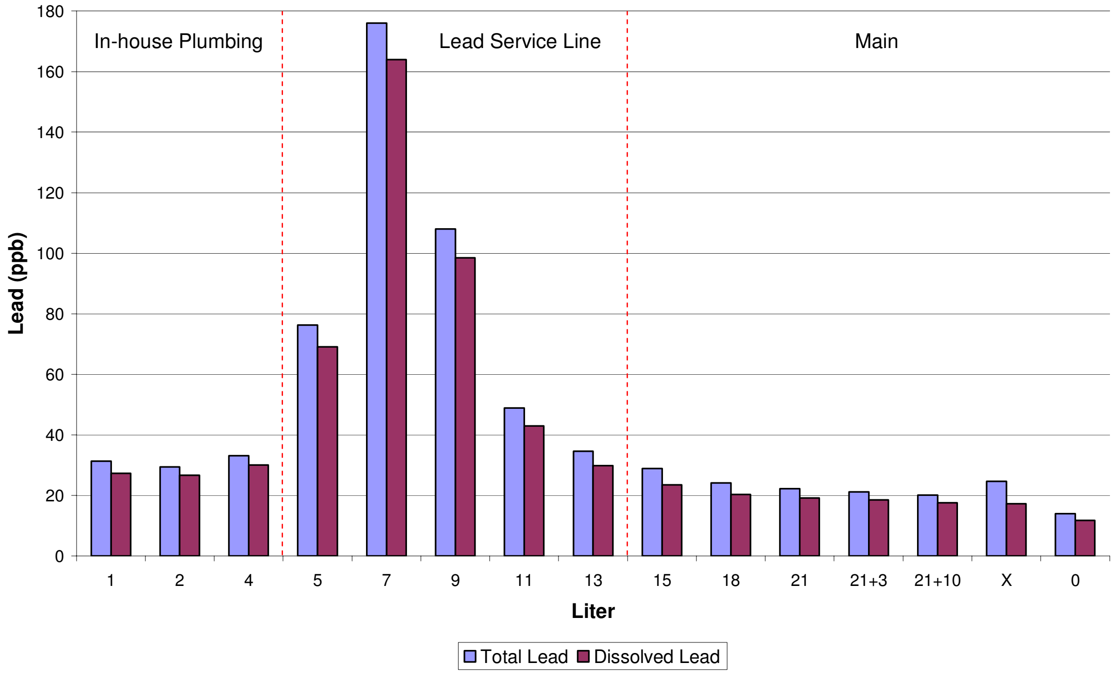
2-9-04 (Profile No. 5)



2/24/04 (Profile No. 6)

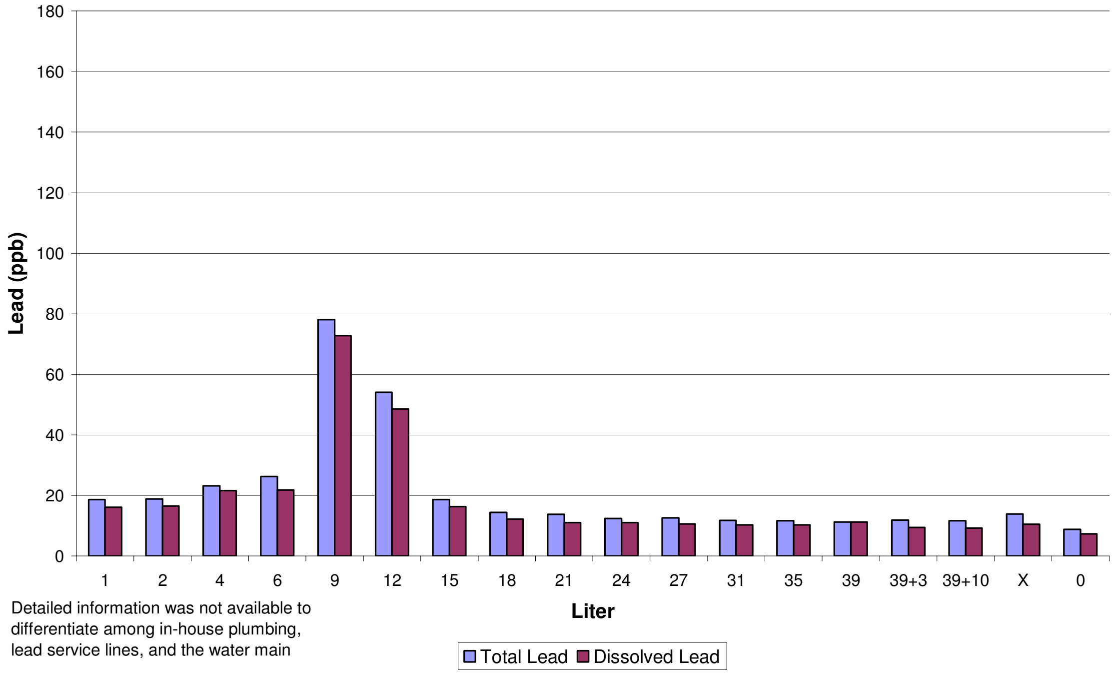


3-2-04 (Profile No. 7)



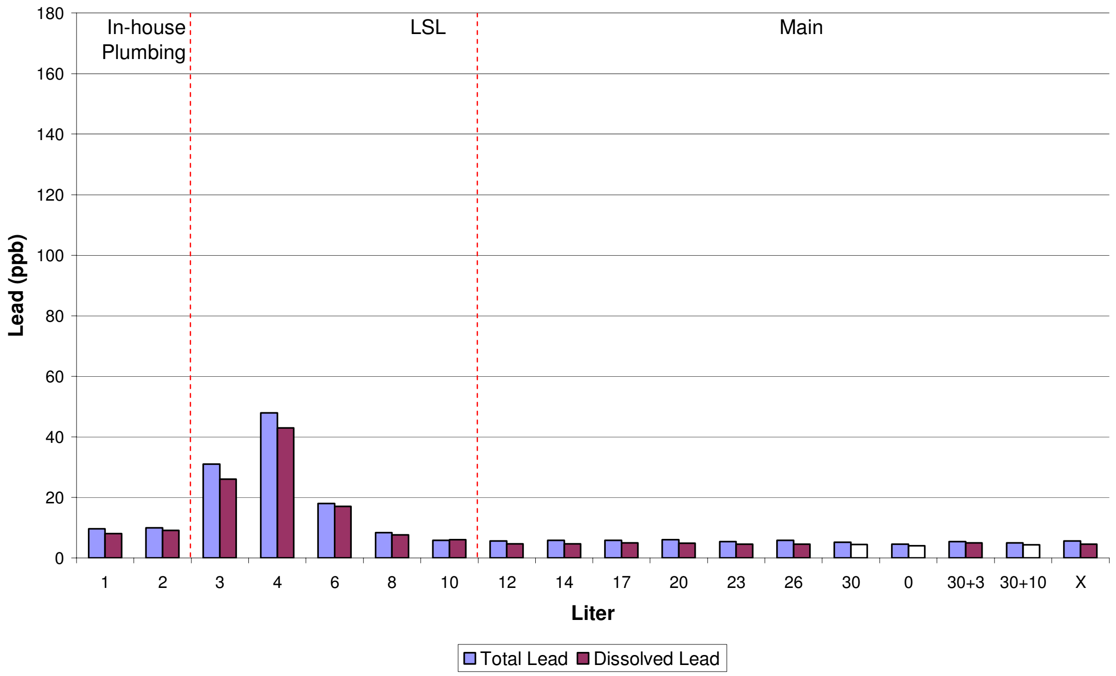
3-9-04 (Profile No. 8)

3-16-04 (Profile No. 9)



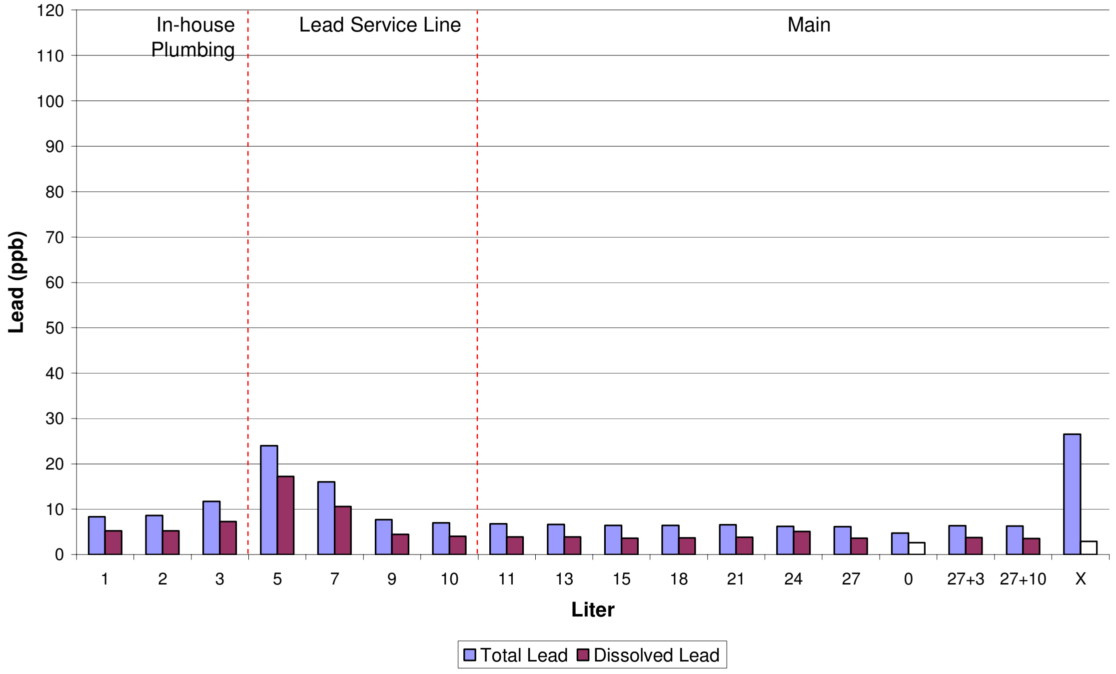
Detailed information was not available to
differentiate among in-house plumbing,
lead service lines, and the water main

3-24-04 (Profile No. 10)

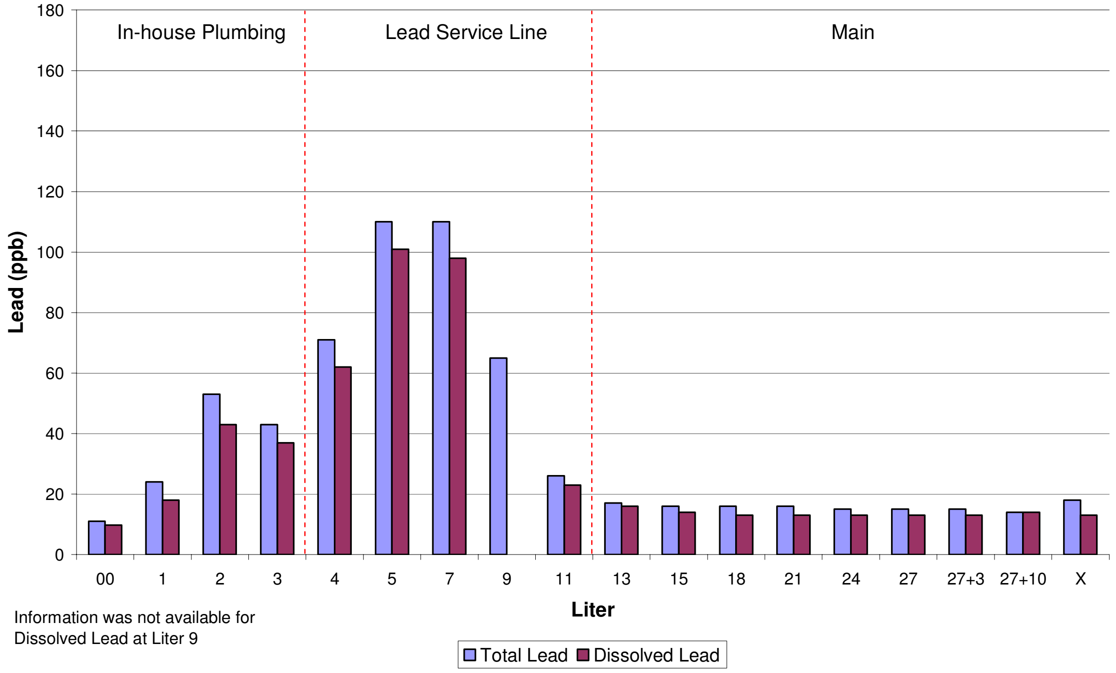


3-24-04 (Profile No. 11)

3/30/04 (Profile No. 12)

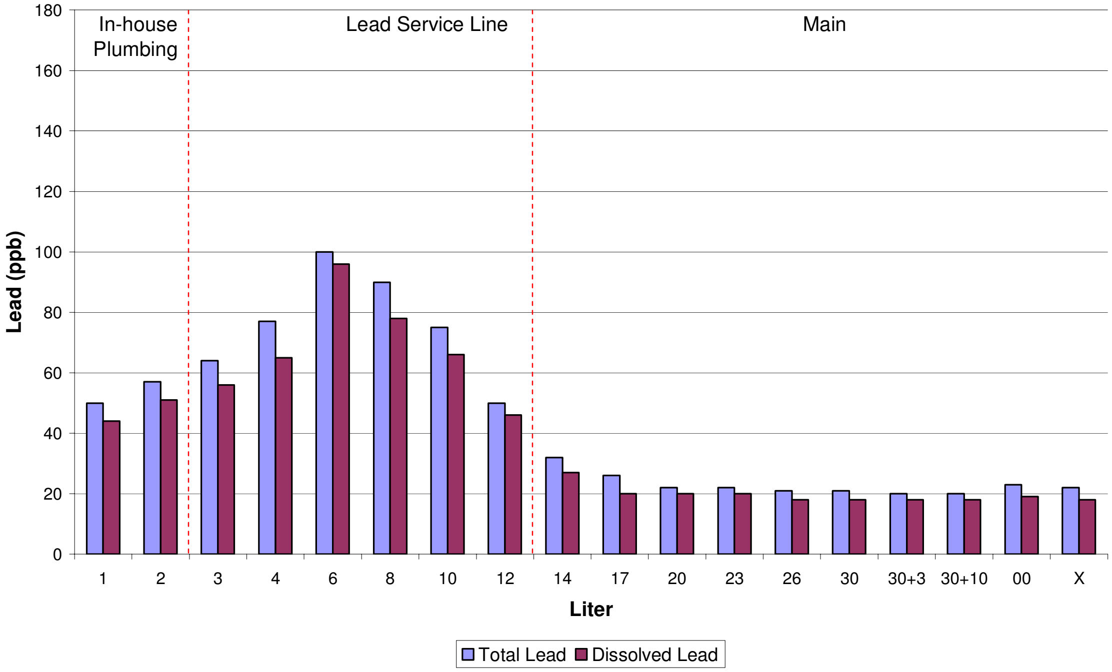


3/31/04 (Profile No. 13)



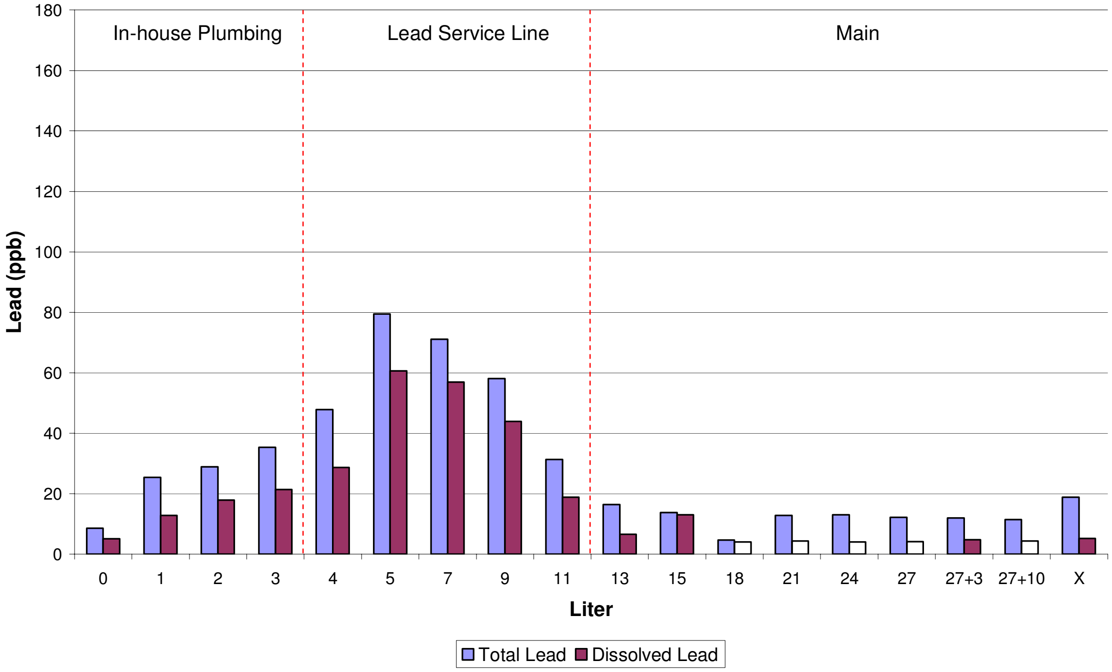
Information was not available for Dissolved Lead at Liter 9

4-1-04 (Profile No. 14)

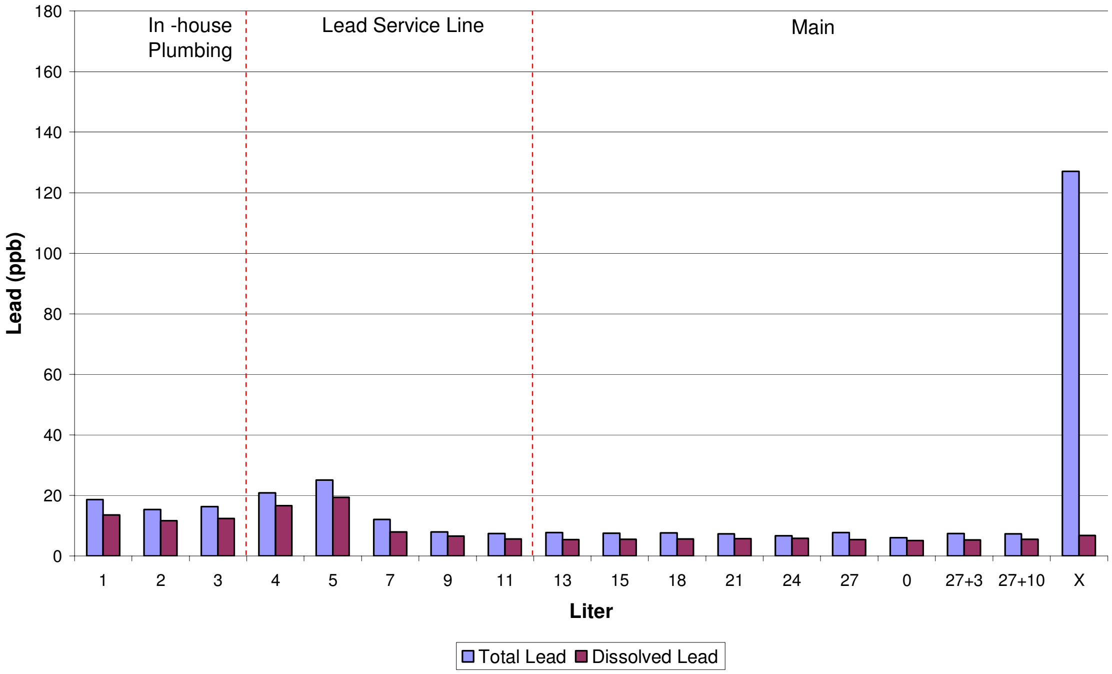


II. Profiles Collected during Chlorine Burn

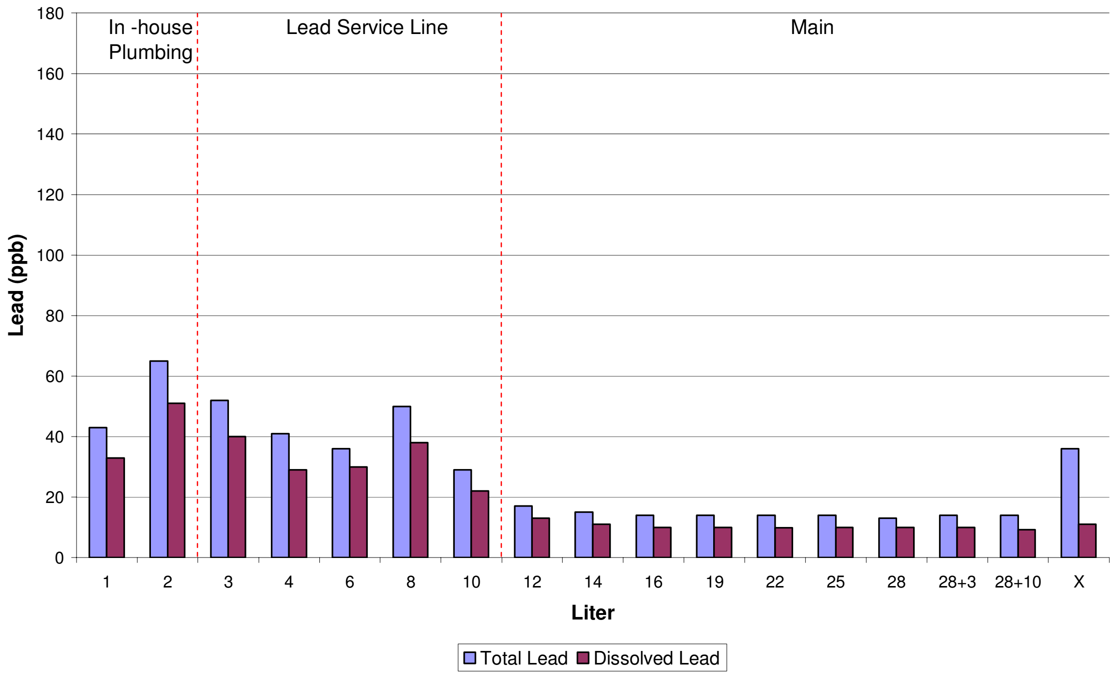
4-5-04 (Profile No. 15)



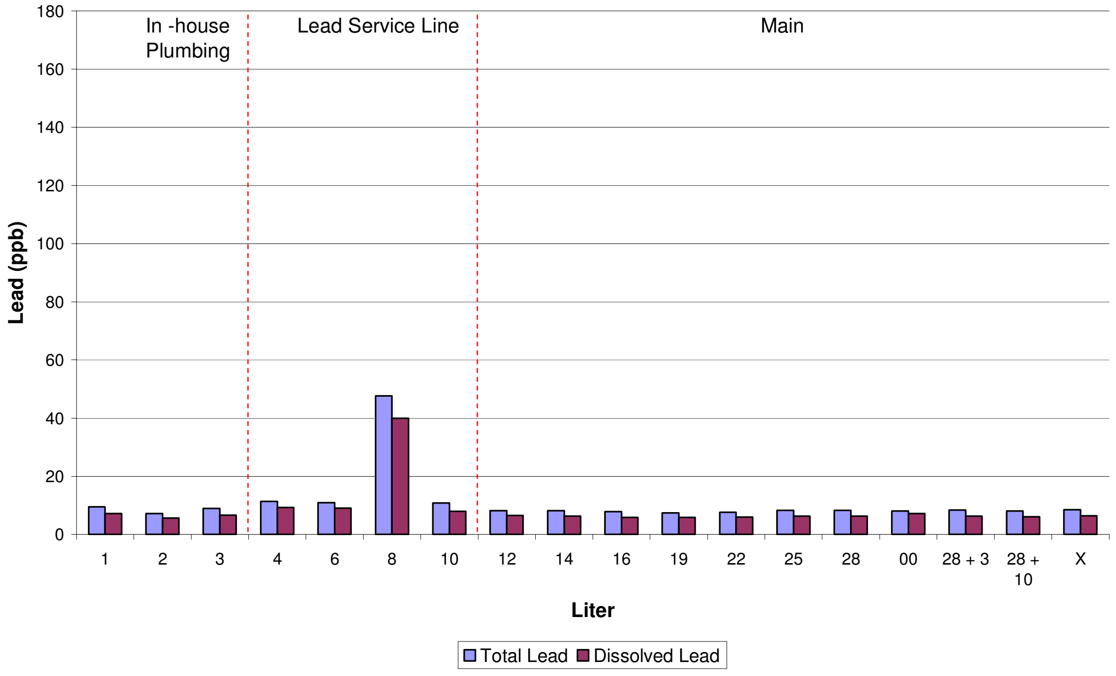
4-6-04 (Profile No. 16)



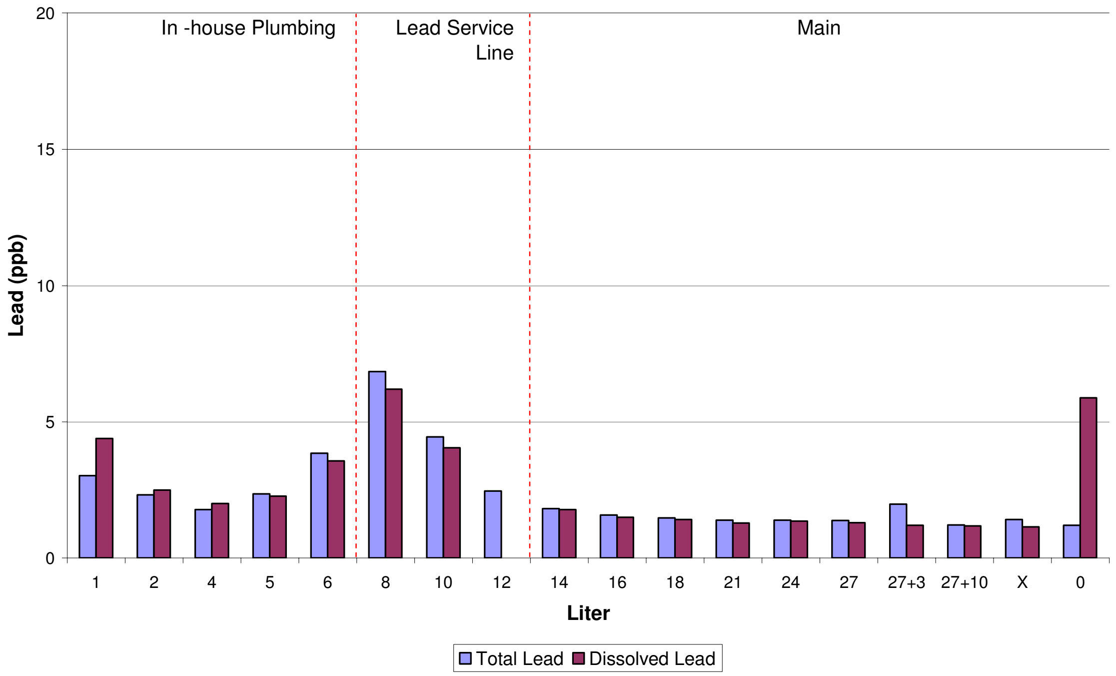
4-6-04 (Profile No. 17)



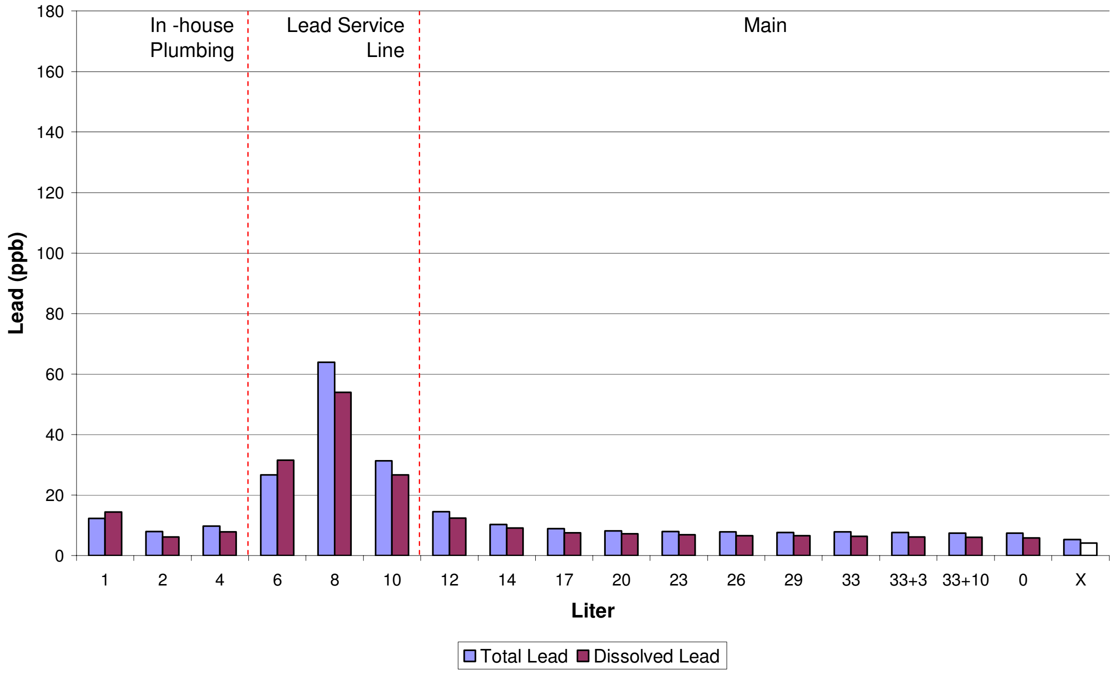
4-13-04 (Profile No. 18)



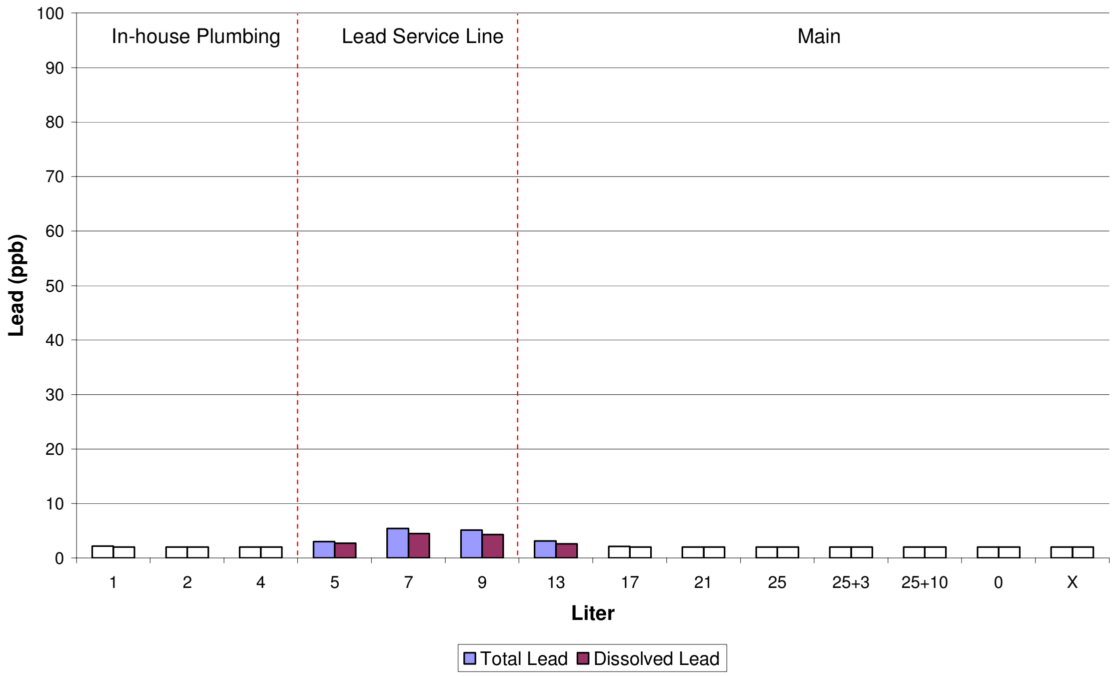
4/26/04 (Profile No. 19)



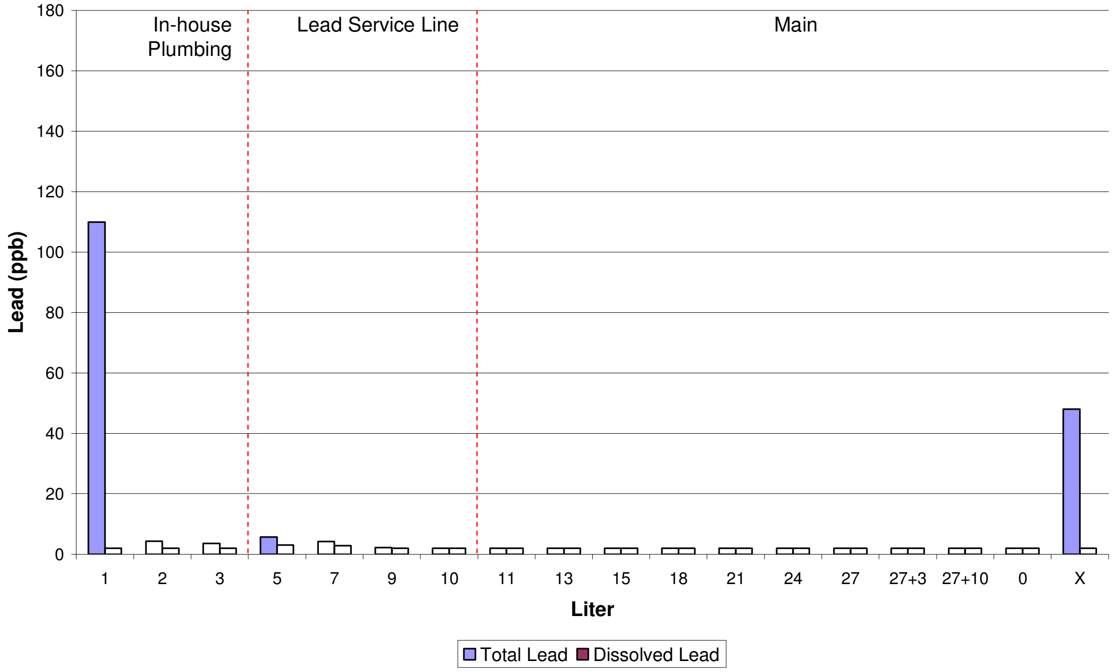
4-27-04 (Profile No. 20)



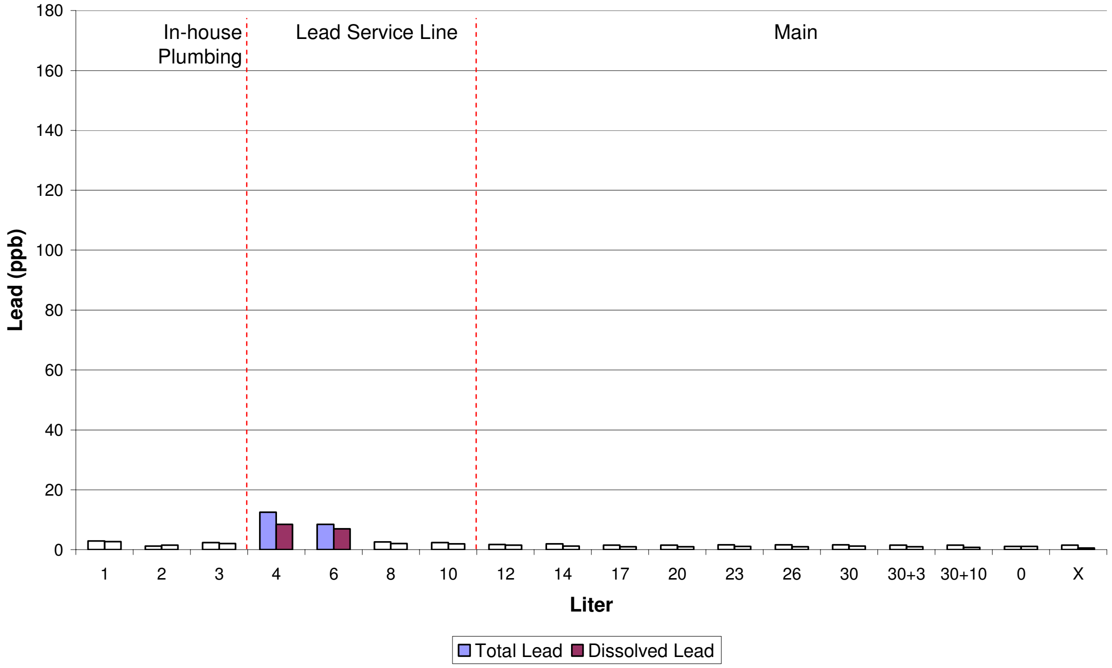
4/29/04 (Profile No. 21)



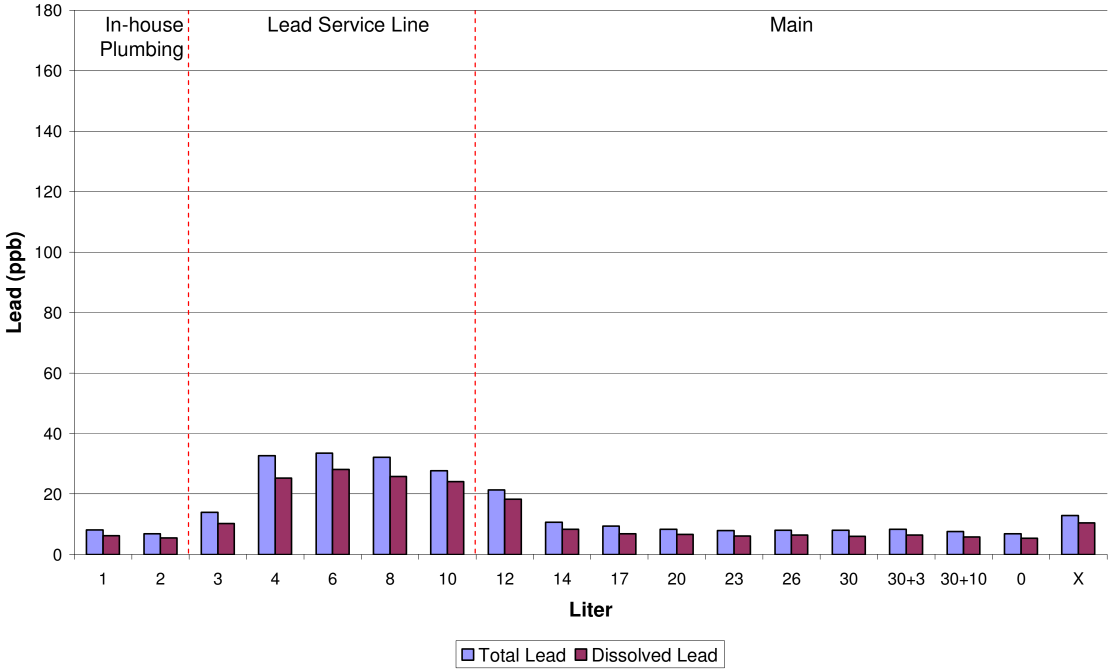
4-30-04 (Profile No. 22)



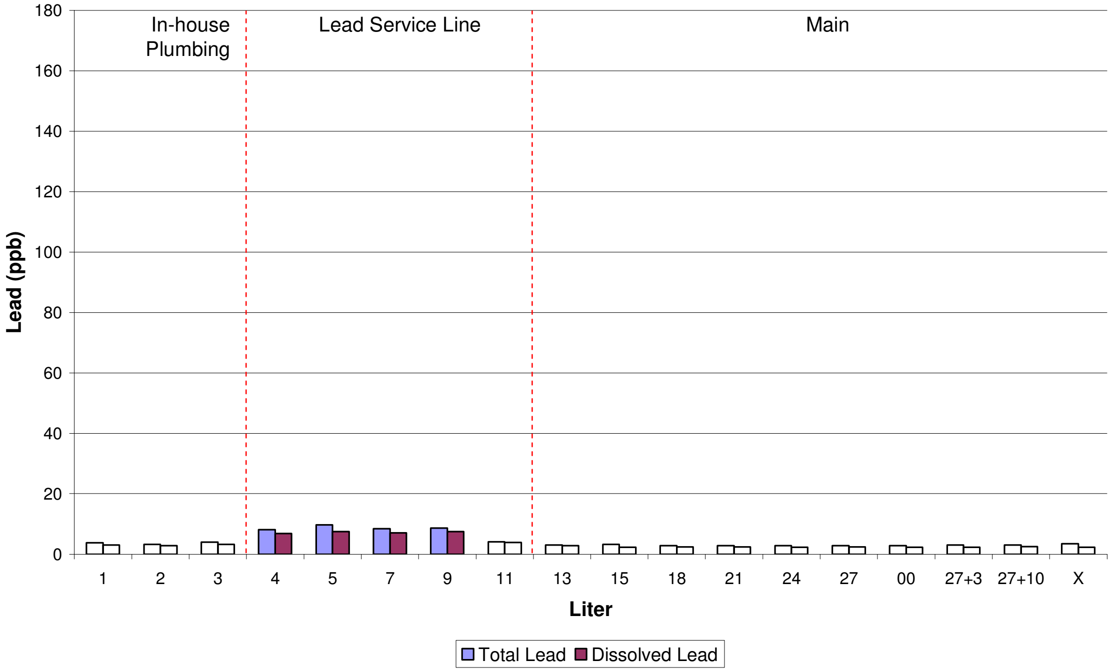
5-3-04 (Profile No. 23)



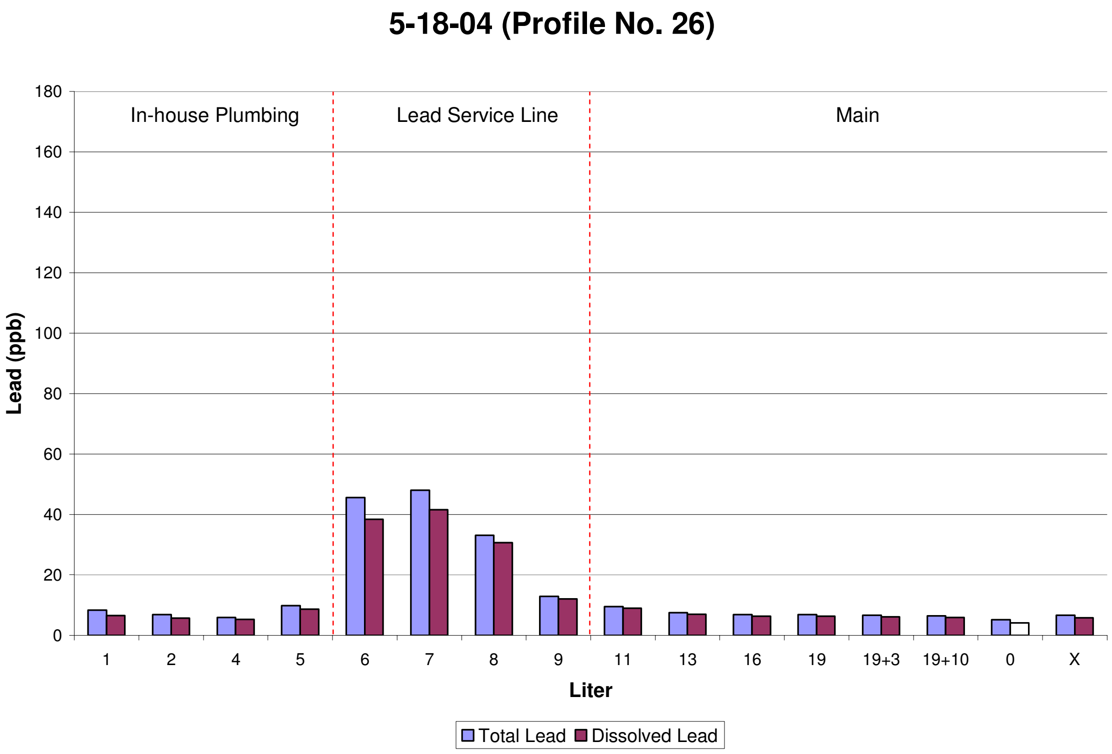
5-3-04 (Profile No. 24)

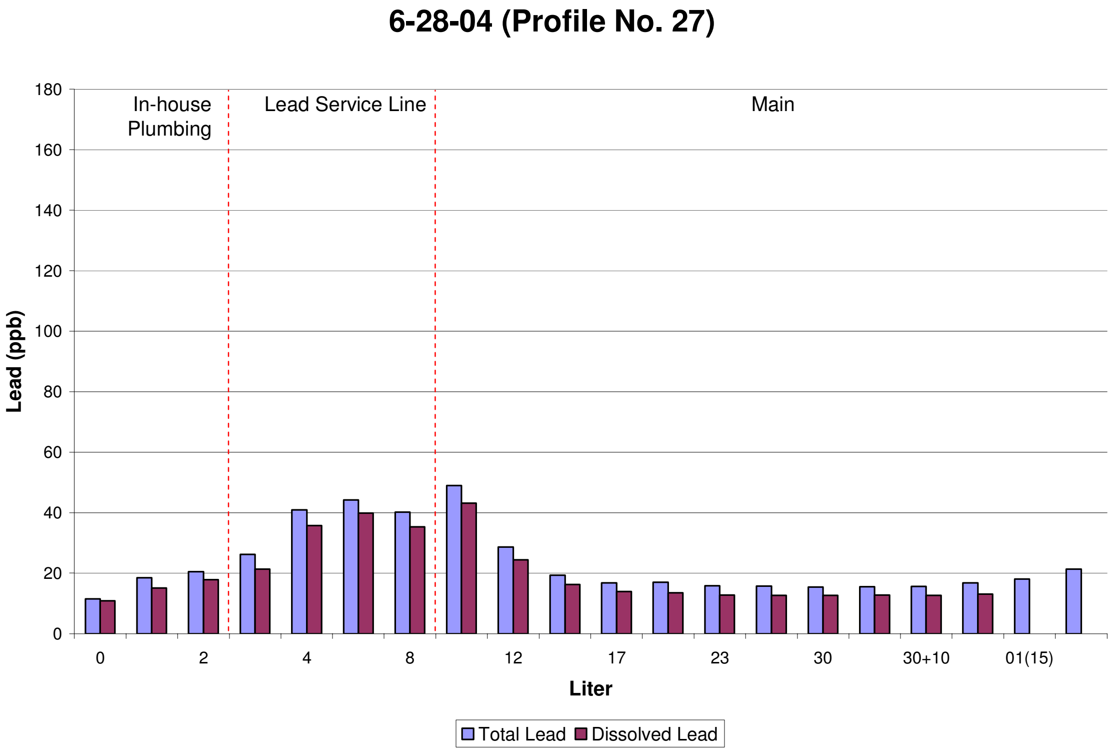


5-7-04 (Profile No. 25)

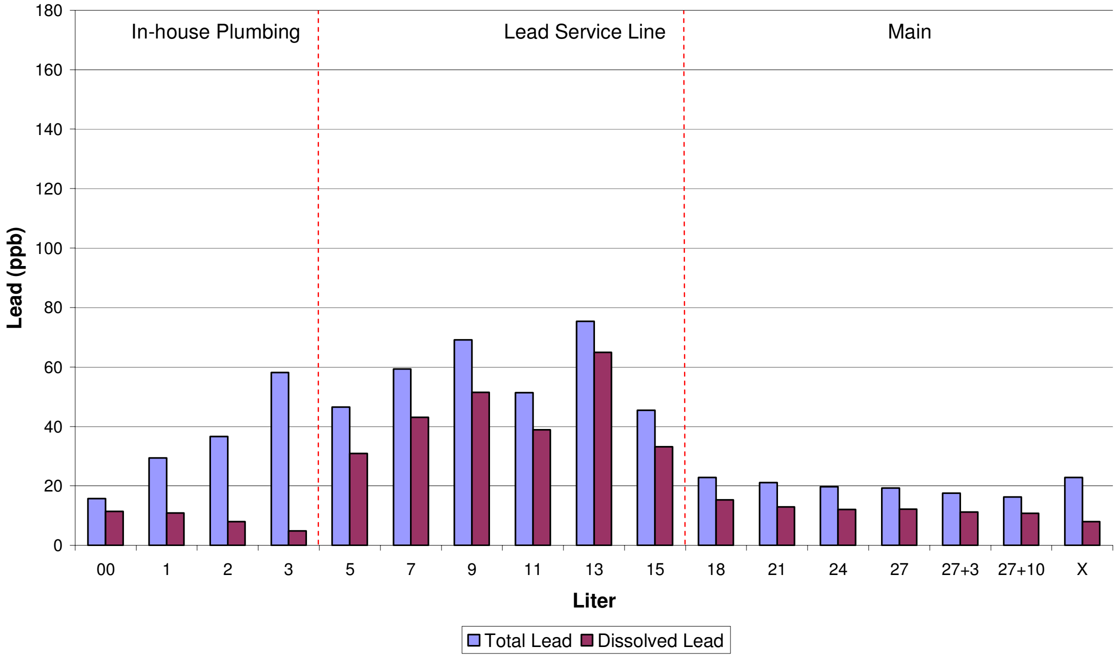


III. Profiles Collected during Chloramination, after Chlorine Burn



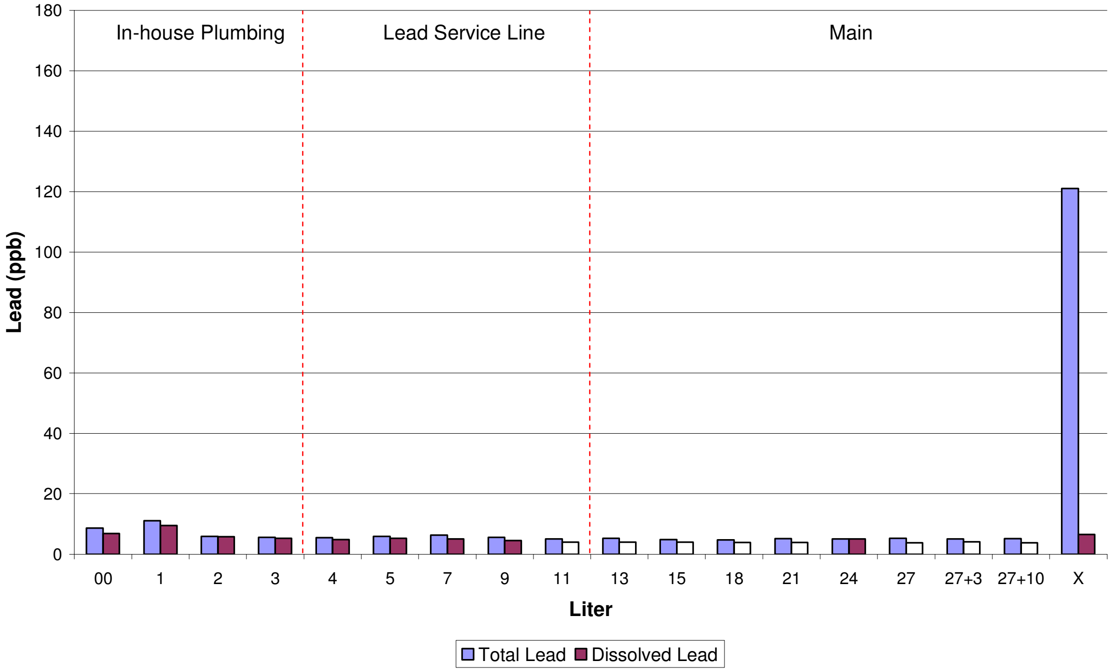


7-6-04 (Profile No. 28)

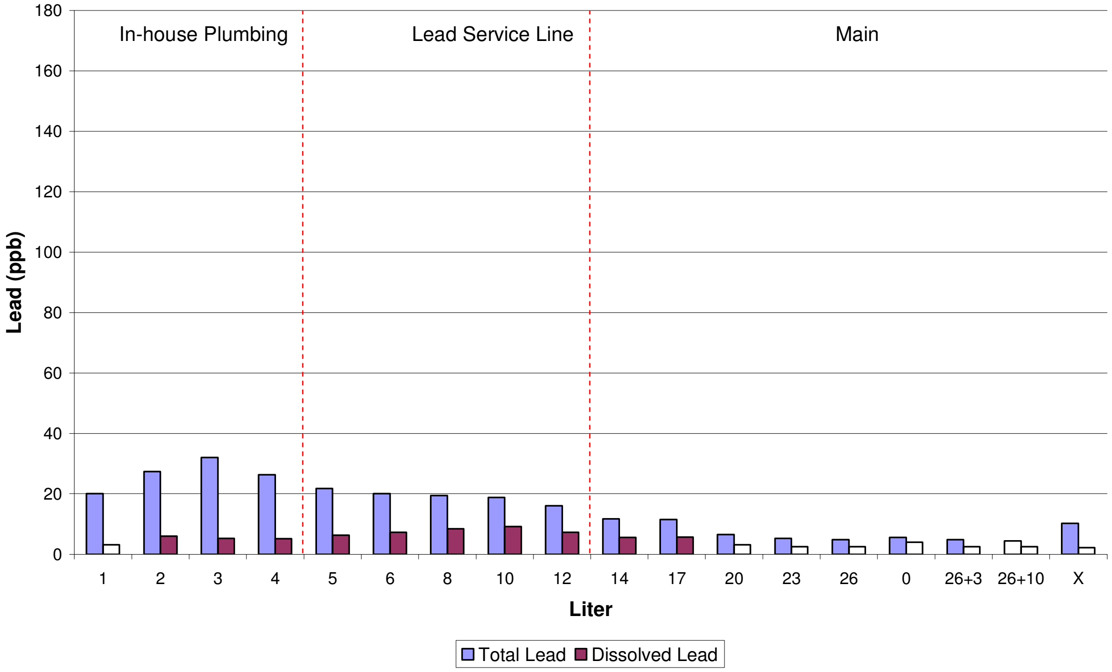


IV. Profiles Collected after Orthophosphate Addition

7-16-04 (Profile No. 29)



11-30-04 (Profile No. 30)



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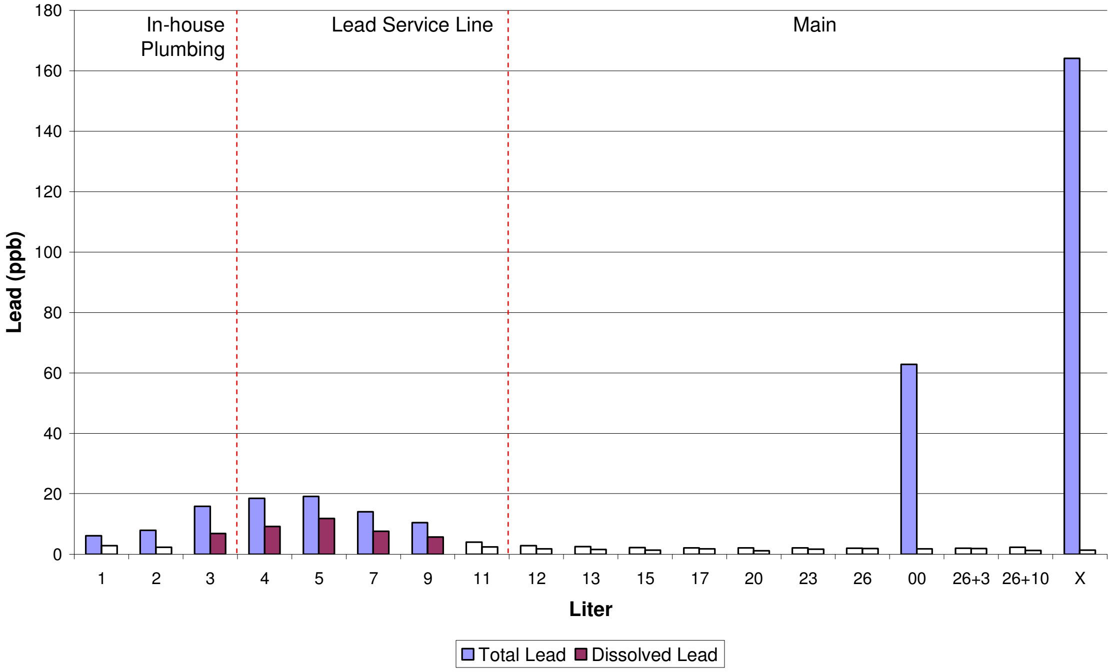

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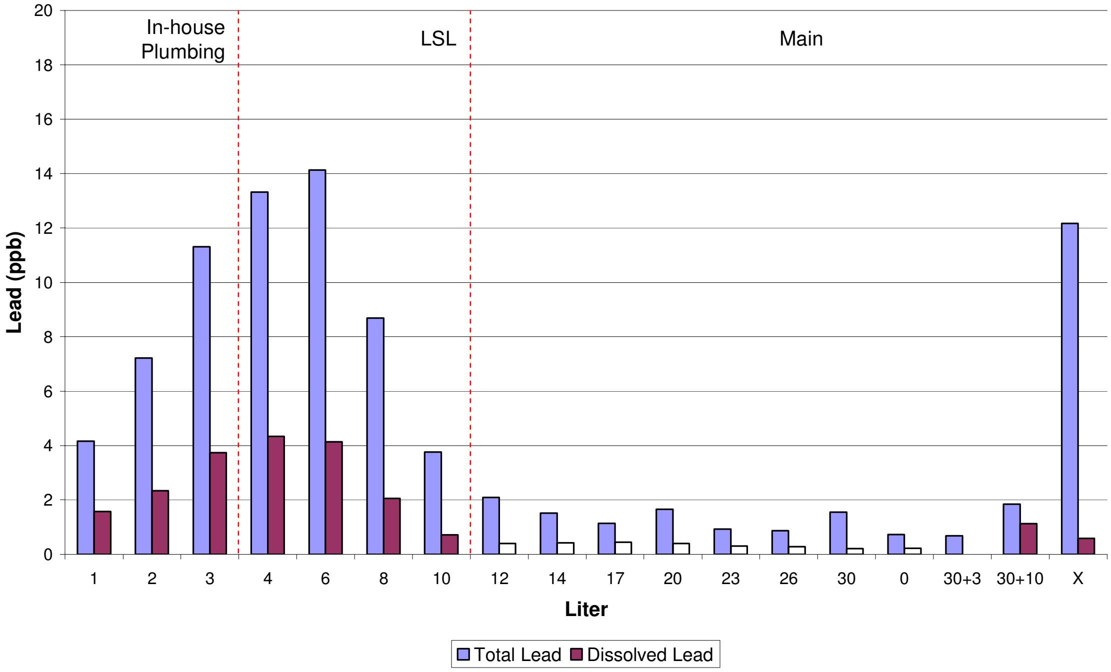

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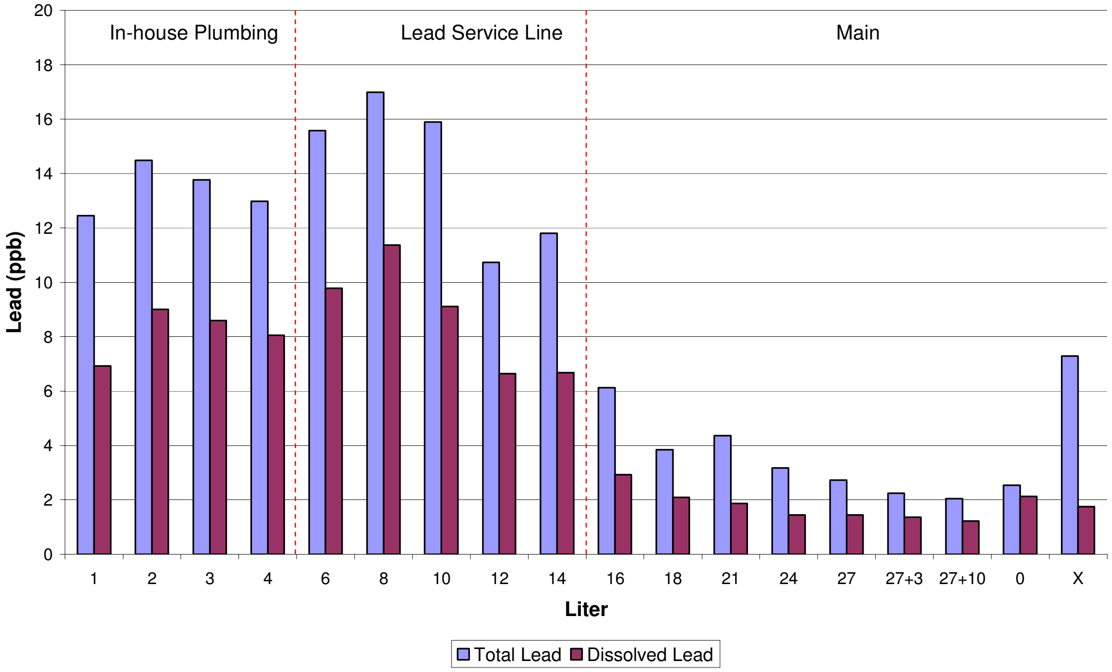

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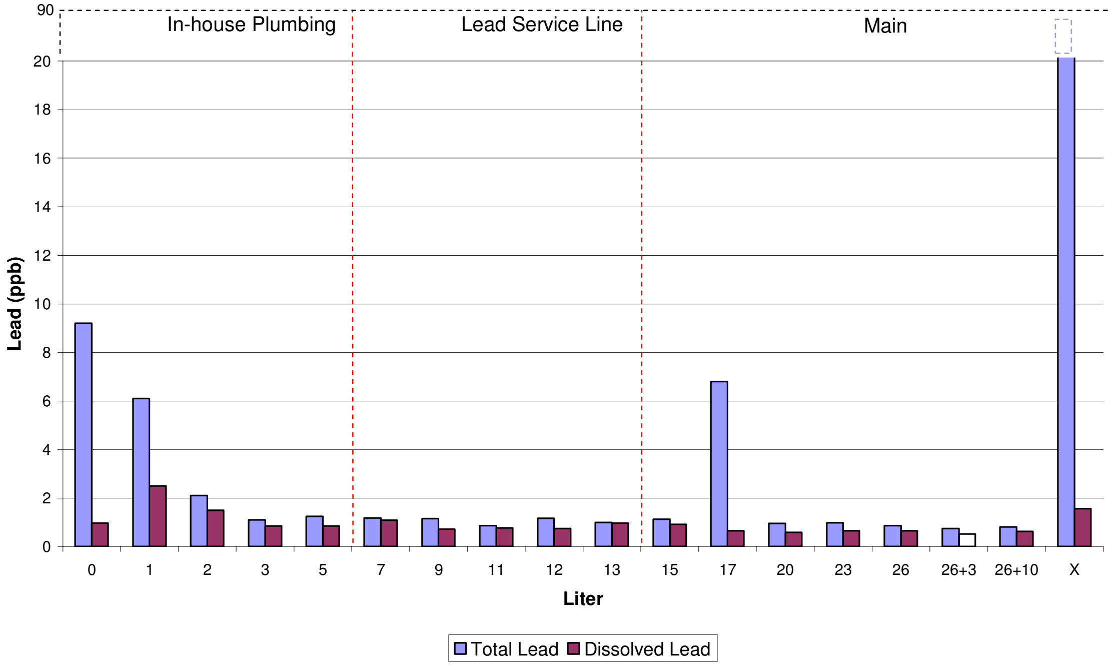

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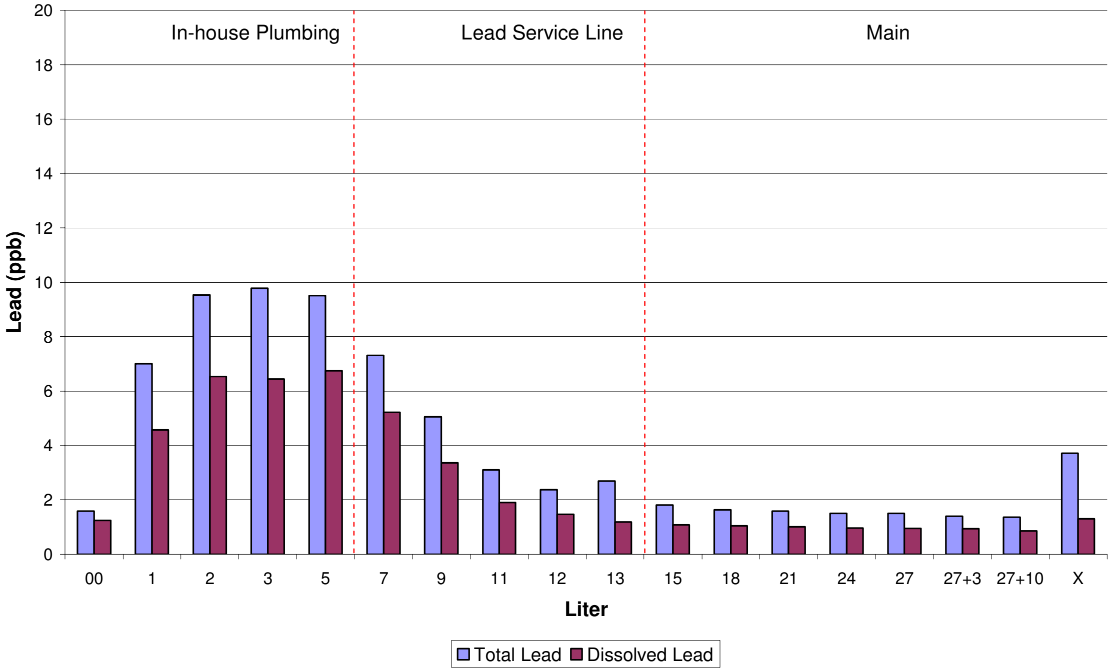

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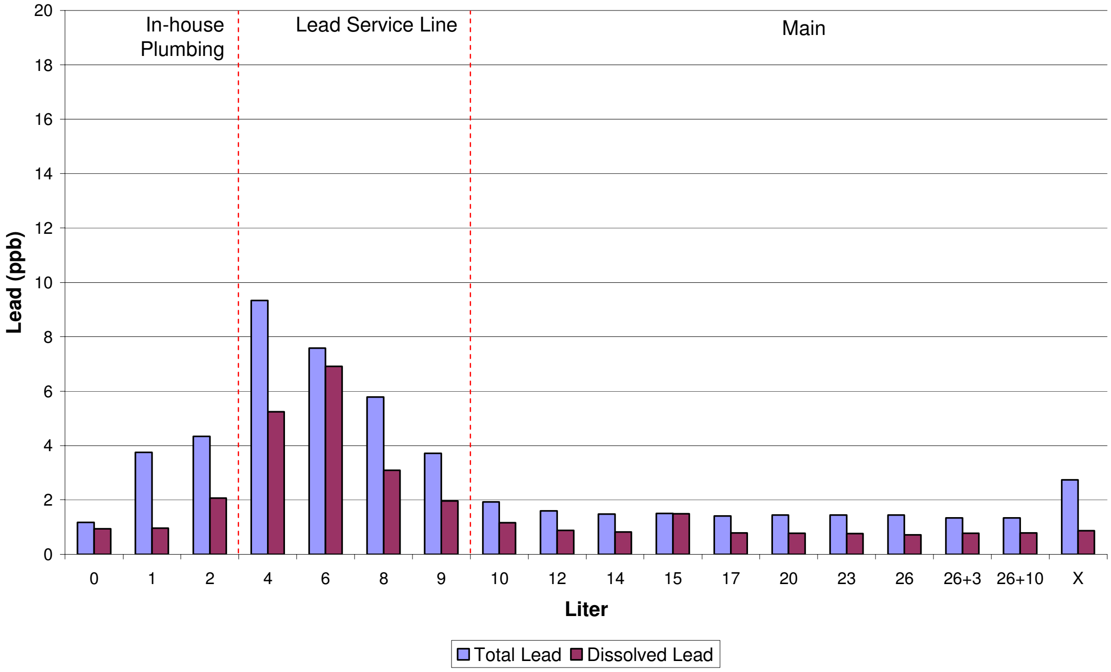

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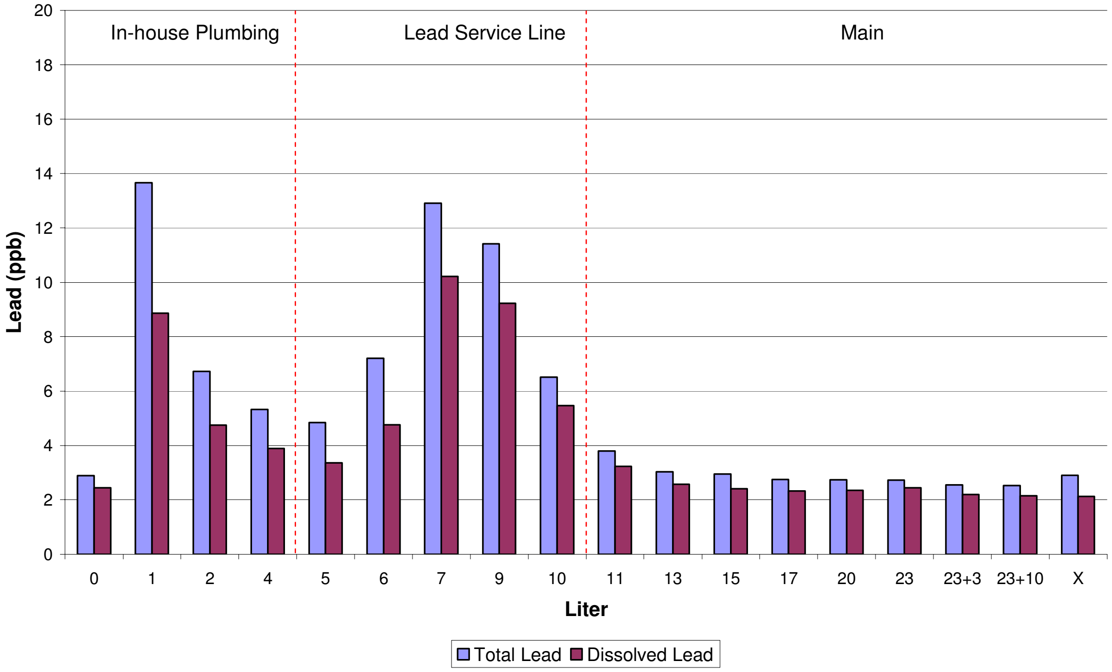

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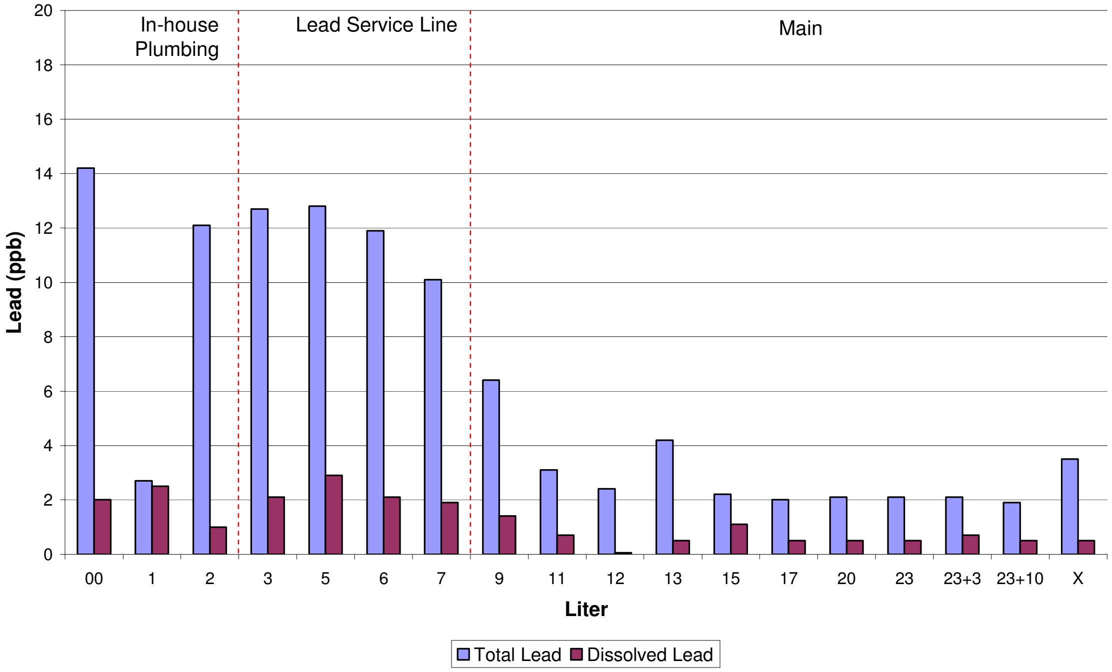

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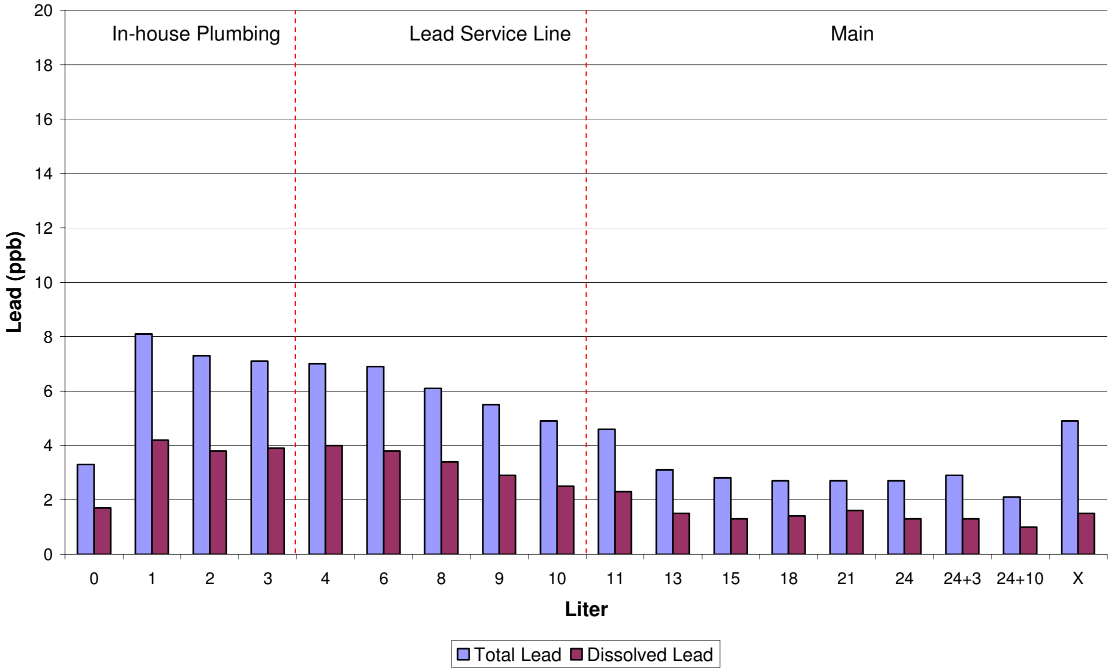

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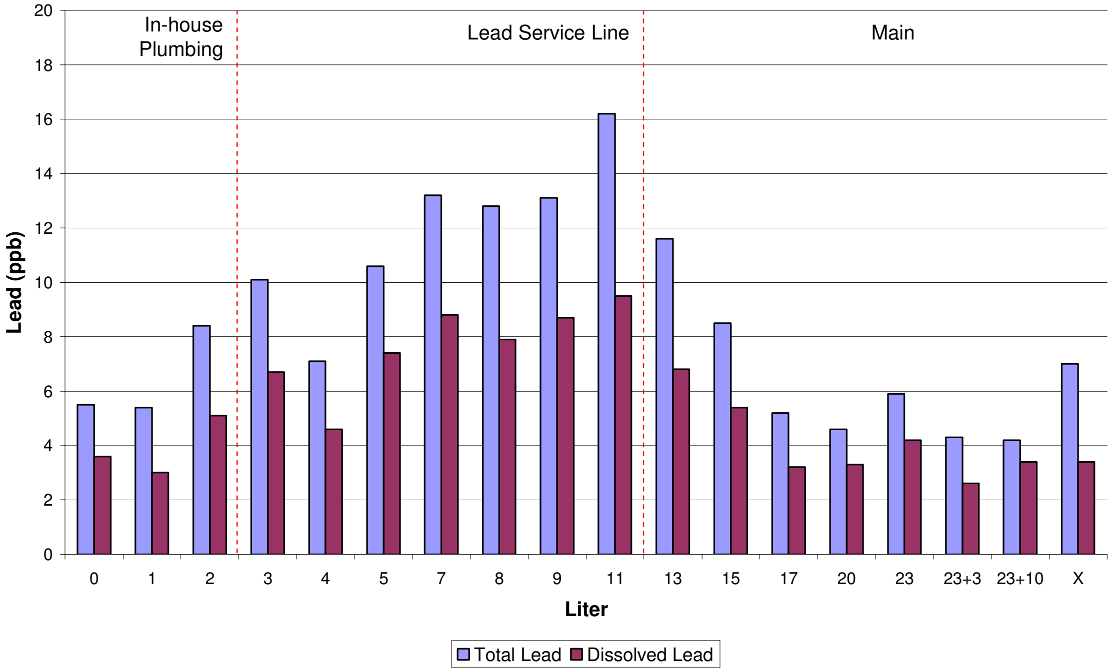

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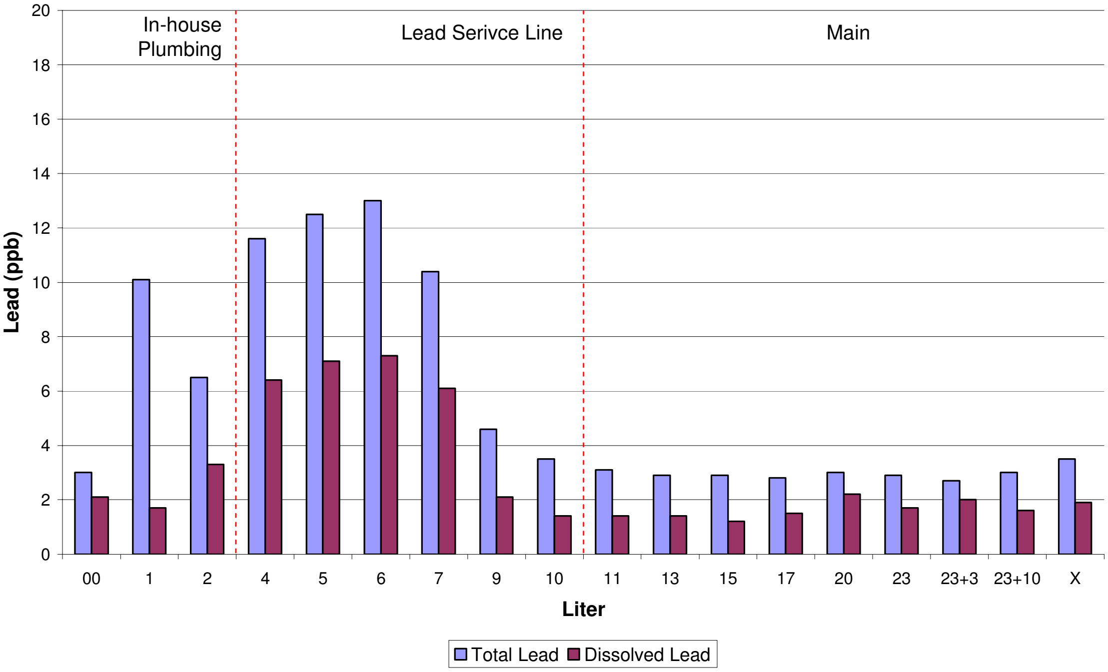

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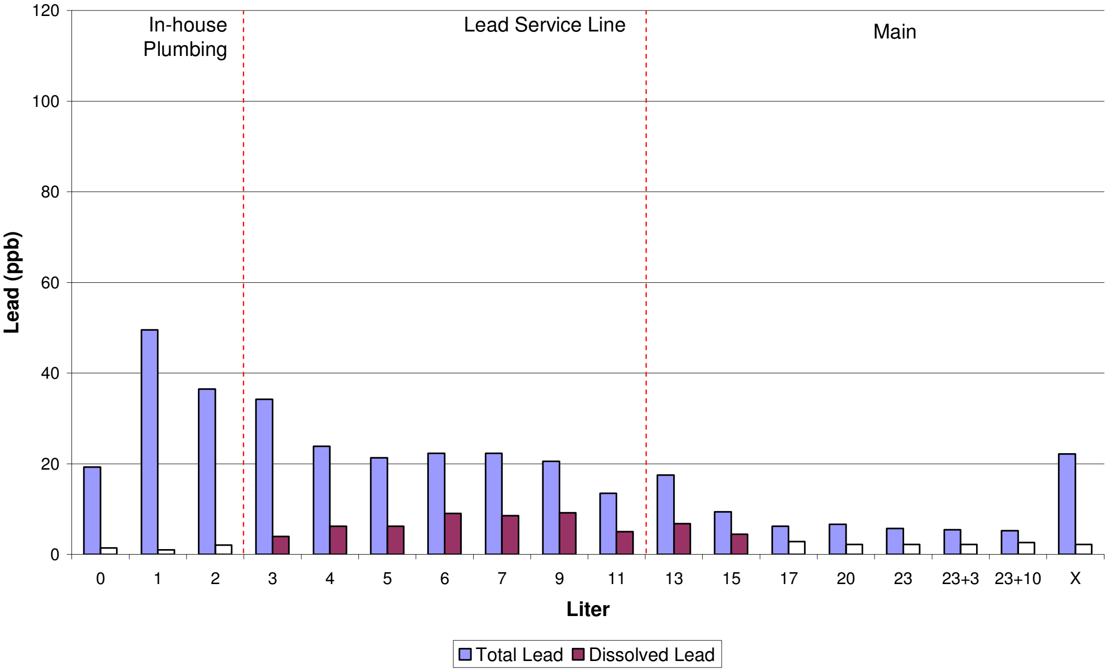

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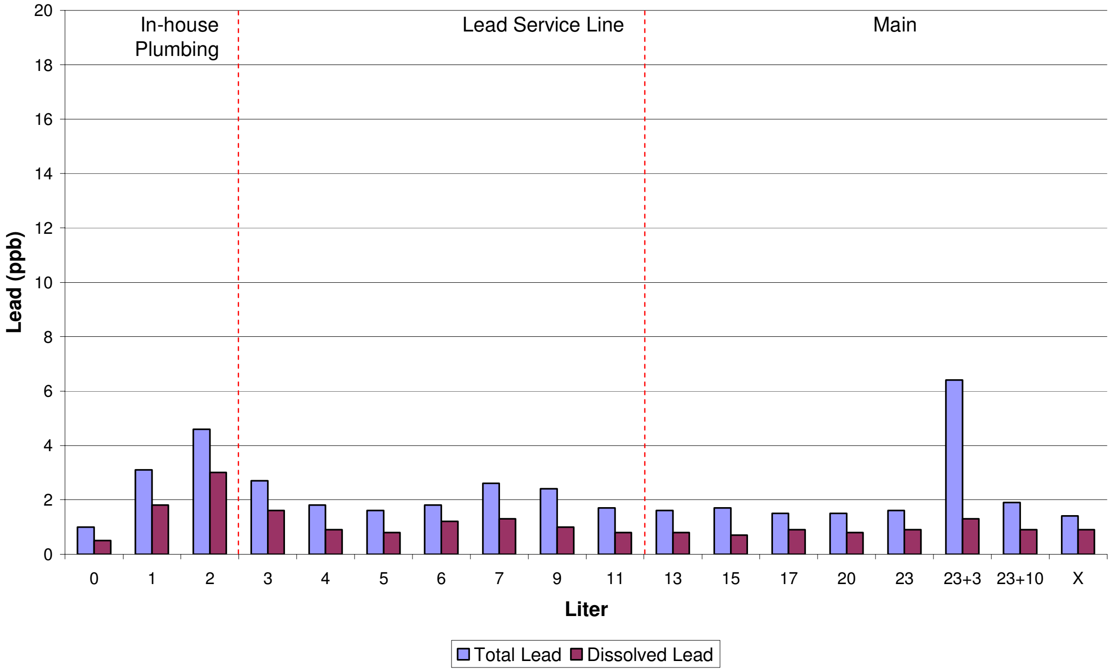

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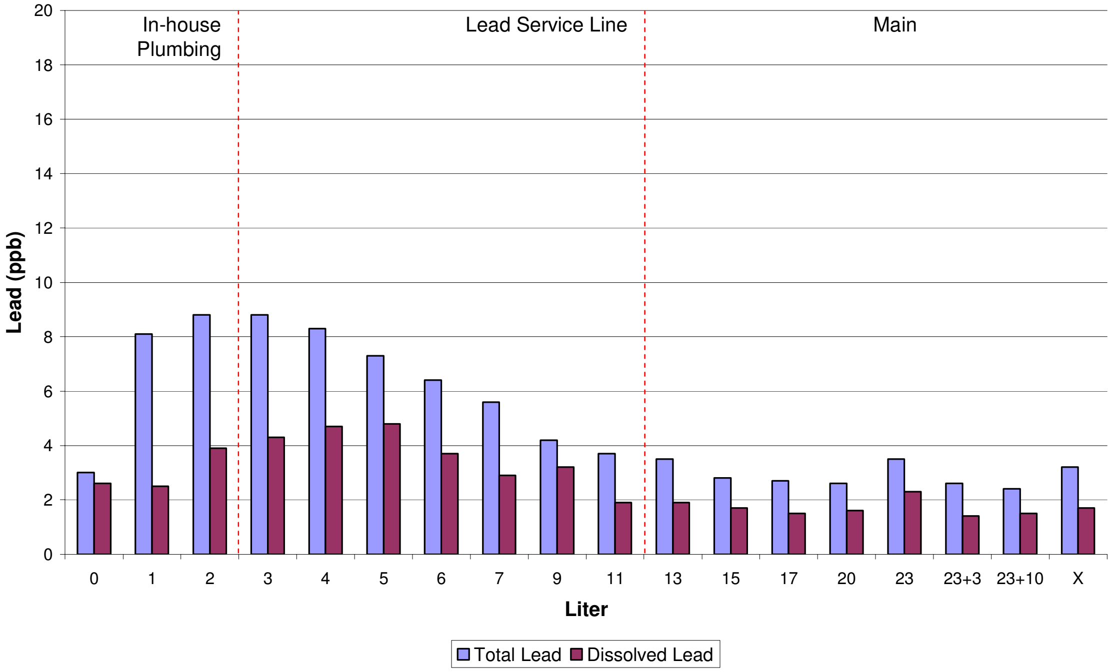

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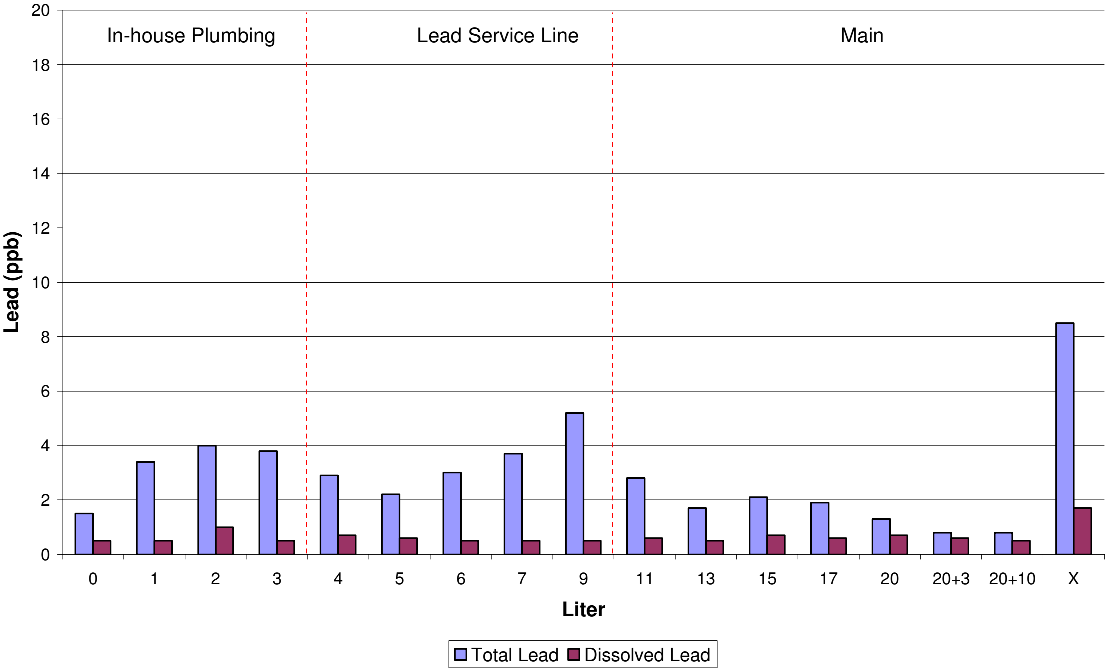

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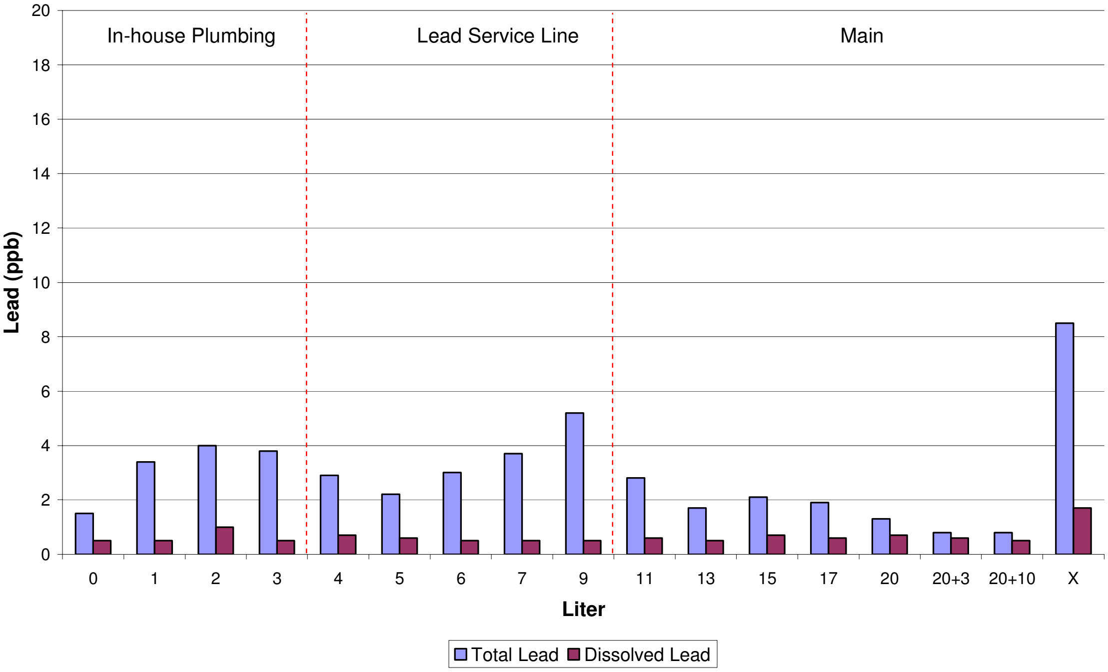

Appendix B

Study Approach

The study was conducted in two steps: 1) gathering, organizing and summarizing the available information, and listing potential causes of elevated lead levels; and 2) evaluating and determining the most probable causes.

Step 1: Gathering, Organizing, and Summarizing Available Information

Based on data and other information provided by EPA, the contractor produced the following:

- Technical memorandum with preliminary findings and identifying additional data needs
- 3-ring binder containing all reports and data gathered and reviewed
- Data evaluation report

Data and information initially provided by EPA to the contractor included the following:

<u>Studies and Reports</u>

- Caustic soda feasibility study, 1998
- Electrochemical pipe loop study on lead leaching rates from lead service line (LSL) coupons under various treatment scenarios
- Sanitary survey reports for WTPs and distribution system since 1990
- Microbial Comprehensive Performance Evaluation (CPE) Report for the treatment plants
- Optimum Corrosion Control Treatment (OCCT) studies and approvals (original 1993-2000, revised 2004)
- Available data from a flow-through pipe loop study looking at corrosion rates under various treatment scenarios (study not yet started- expected completion June 2005 at earliest)
- Lead in Water Survey – 1990 materials survey estimating LSLs and other sources of lead in the distribution system
- LSL partial replacement method study – study conducted that looked at three methods of cutting pipe and thorough flushing: homes were “profile sampled” before and for two weeks after the partial LSL replacement work, May 2004

<u>Treatment Related Data and Information</u>

- WTP treatment schematics and chemical dosing information
- Raw and Finished Water Parameters from both WTPs
  - Monthly average and maximum flow rates
  - Monthly average pH
  - Free and total ammonia
  - Free and total chlorine
  - Monthly average alkalinity as $CaCO_3$
  - Calcium
  - Conductivity
  - Magnesium

  - Temperature
  - Calcium hardness, both total and dissolved
  - Total coliform bacteria
  - Fluoride
  - Dissolved, suspended and total solids
  - Bromide
  - Chloride
  - Sulfate
  - Total Organic Carbon – raw, settled and filtered
  - Metals (EPA method 200.8)

- Entry Points to the Distribution System:
  - Haloacetic Acid (HAA5), total and individual concentrations
  - Total Trihalomethanes (TTHMs) and four individual trihalomethanes (THMs)

<u>Distribution System Data and Information</u>

- Distribution system atlas or atlases
- Total coliform (presence/absence)
- LCR water quality parameter data: pH, alkalinity, calcium
- HPC bacteria – limited data in terms of locations and monitoring duration
- TTHM and HAA5
- Nitrate and nitrite, both measured as Nitrogen
- Metals
- Lead first draw (LCR compliance)
- Lead second draw (earlier years, this was the second liter of water; changed in 2003 to represent water sitting in the service lines)
- Lead profiling data (conducted from late 2003 through August 2004) performed at customer homes to collect every liter of water from the tap out through the water main
- Lead first and second draw customer service samples, February 2003-present.
- LSL replacement samples from LSLs that were not replaced 2003-2004

Step 2: Evaluating and Determining Probable Causes

<u>Completed Data Review</u>

Based on additional data identified in Step 1 and then provided by EPA to the contractor, the data review was completed.

Additional data requested by the contractor as part of step 1, and provided by EPA to the extent it was available, included:

- Data free chlorine and chloramines at entry points to the distribution system and within the distribution system, 1994-2004 (or most current) DC WASA dates of periodic free chlorine use, 2001-2004 (or most current)
- Additional lead profiles in DC WASA system
- Inventory of partial LSL replacement, 1999-2004 (or most current)

- Meter specifications
- Alkalinity data for distribution system entry points, 2000-2001
- Source water quality data 1996-1998; 2003-2004 (or most current)

Statistical Analyses

The contractor performed various statistical analyses on water quality data to determine correlations that could be made regarding the causes for elevated lead levels.

Evaluation of Causes

The contractor evaluated potential causes in two ways:

1. The likelihood of being a significant factor in lead release and uptake by the water
2. The magnitude of the release in relation to the lead level at the tap

For example, the uptake of lead by the water exposed to a water meter might be significant and well documented. However, the contribution of that small segment of water to the elevated lead at the tap might be small. Thus, in this instance, the conclusion would be that water meters are not a significant cause of elevated lead at the tap.

Report

The contractor provided a draft report that included information and findings of both steps 1 and 2 for EPA and peer review comments.

Appendix C

Peer Review of Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events

July 5, 2007

Horsley Witten Group, Inc.
90 Route 6A
Sandwich, MA 02563

Prepared for:

United States Environmental Protection Agency
Office of Ground Water and Drinking Water

Peer Review Report of the Draft Study of Potential Causative Events from Elevated Lead in D.C. Drinking Water

Contents of document:

1. Summary of peer review process and associated documentation

The EPA study: “Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events”, documents a detection of lead in the District of Columbia Water and Sewer Authority’s (DCWASA) water delivery system. DCWASA exceeded the 15-µg/L action level (AL) for the Lead and Copper Rule during July 2000 to June 2001 at the 90th percentile in home tap sampling, and repeatedly exceeded the AL during subsequent monitoring through the period ending December 2004. This study evaluates the potential causative events and parameters contributing to the elevated lead levels in the D.C. drinking water system.

EPA hired a contractor, Horsley Witten Group, Inc. (H&W), to facilitate a peer review of the study in accordance with the "Peer Review Handbook", 3rd Edition, EPA 100-B-98-001, hereinafter, "Handbook”). The peer review is intended to provide a focused, objective evaluation of the study and causative events leading up to the contamination incident. EPA addresses the criticisms, suggestions, and new ideas provided by the technical reviewers prior to redrafting the reviewed work. Comprehensive, objective technical reviews contribute to good science and regulatory acceptance of precedent-setting methodologies and controversial issues within the scientific and regulated communities.

H&W began the review process by reviewing the recommended list of potential reviewers provided by EPA and selecting 3 peer reviewers to review the document. Two of the three reviewers were selected based on their scientific or technical expertise in issues associated with lead corrosion in distribution and plumbing systems. The third reviewer is a representative of a drinking water utility with relevant experience. Reviewers were screened for potential conflicts of interest, as specified in the Peer Review Handbook. H&W queried reviewers to determine their availability to participate in the review, and found two of the three chosen reviewers had scheduling conflicts and could not participate. H&W found two reviewers of equal expertise, with no conflicts, to replace the initially chosen reviewers. A revised reviewer list was developed and forwarded to the WAM for approval on April 6, 2007.

After receiving approval of the list of reviewers, H&W emailed the reviewers one electronic copy of the pre-decision draft document entitled “Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events” dated February 23, 2007, along with one electronic copy of the Peer Review Charge, instructions, and appendices. H&W contacted reviewers periodically throughout the review period to answer any questions reviewers had, and to determine whether reviewers would indeed be able to provide comments by the set deadline of April 20, 2007. H&W received reviewers’ comments, compiled comments into an EPA-approved format, and submitted each comment document to EPA.

H&W compiled and maintained a record of all potential peer reviewers, including names, affiliations, addresses, phone numbers, qualifications, and potential conflicts of interest.

H&W has obtained agreements to honor confidentiality from reviewers, since the review document is a pre-decisional draft not for general public distribution. An explanation of such was included in both H&W's subcontract to reviewers as well as a letter of instruction.

H&W assembled the peer review record, which consisted of: the draft work products reviewed; the Charge; all materials provided to the reviewers; and reviewer comments. H&W submitted the peer review record to EPA on May 3, 2007.

Information on the areas of expertise, the names, affiliations, and resumes of the selected peer reviewers are included in this document in Appendix I.

The peer reviewers' comments are provided in Appendix II.

2. Summary Table of Expertise Criteria and Selected Peer Reviewers' Names and Affiliations

Peer Reviewers of "Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events"

Criteria for Selecting Peer Reviewers	Peer Reviewer
Scientific/technical expertise regarding lead corrosion in distribution and plumbing systems.	Carol Rego, CDM
Chief Operating Officer of a major drinking water utility.	John S. Young, Jr. American Water
Scientific/technical expertise regarding lead corrosion in distribution and plumbing systems.	John F. Ferguson, Ph.D. University of Washington

3. Peer Review Charge

Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events

Background

In 2004, EPA convened a series of expert workshops in light of concerns raised about the effectiveness of the Lead and Copper Rule (LCR). The recommendations from these workshops led EPA to consider several actions, which included short-term and long-term revisions to the LCR, additional expert workshops, new and expanded guidance, and additional research. In terms of additional research, EPA identified a need to perform an in-depth analysis to document and determine to the extent possible the cause or causes of elevated lead levels in the District of Columbia (D.C.) drinking water.

Immediately prior to 2000, D.C. drinking water did not typically show lead levels that exceeded the LCR action level of 0.015 mg/L. On November 1, 2000, the Washington Aqueduct, which operates the Dalecarlia and McMillan Water Treatment Plants, switched from free chlorine to chloramine disinfection. Since early 2001, the D.C. Water and Sewer Authority (DCWASA) reported some elevated lead levels in drinking water samples from D.C. residents' taps.

This study documents and evaluates the potential causative events and parameters contributing to the high levels of lead in D.C. drinking water. Section 1 provides a summary of the document, including background information. Sections 2, 3, and 4 provide background information on the lead monitoring program, water treatment facilities, and distribution system conditions. Section 5 discusses the following causative factors along with the likelihood of each contributing to the situation:

1. Lead release from piping systems
2. Conversion from free chlorine to chloramines for final disinfection
3. Water quality parameters in the distribution system
4. Other lead-bearing materials
5. Galvanic corrosion of lead service lines
6. Effect of grounding currents on lead-bearing components
7. City-wide meter replacement program
8. Drought conditions and effects on corrosivity of DCWASA water

The study concludes that (1) the primary source of lead release was attributed to the presence of lead service lines (LSLs) in the DCWASA distribution system, and (2) the major causative factor of high lead levels at the consumers' taps was likely the change in oxidation state (as indicated by ORP) resulting from the conversion from free chlorine to chloramines. The relatively high concentration of free chlorine that was used for residual disinfection prior to the conversion to chloramines likely facilitated the formation of Pb (IV) species in the DCWASA distribution system. Additional contributing factors were likely related to low operating pH levels and pH variations in the distribution system which, based on conventional understanding of Pb (II) solubility per the LCR, would lead to greater Pb (II) release. Faucets, solder, and other home plumbing components likely contributed, but were not the major source of lead release to DCWASA tap samples.

Please find attached a copy of the draft study and appendices for your review. This version of the report reflects Agency comments received on an earlier draft. We expect that this version of the report, with some additional minor modifications, will be the final version. Your comments will be useful in preparing the final version of the report and discussing the findings of the study with the public.

To assist in your review of the study, we ask that you pay particular attention to the following questions:

a. Does the study consider potential causative events that are appropriate? Are the causative events and factors considered all relevant to the purpose of the study? What additional causative events or factors, if any, should be considered?

b. Does the study consider each causative event adequately? Is the data presented all relevant to the purpose of the study?

c. Do the data and analyses support the conclusions? Are there additional analyses that could better support the conclusions? What additional conclusions, if any, can be reached based on the data and analyses?

d. Section 6 of the study identifies possible follow-on work based on available findings and conclusions drawn from the study. Which, if any, of the recommended follow-on work should EPA undertake? What additional follow-on work and/or research should EPA undertake as a result of this study?

Appendix I: Peer Reviewer Credentials

General Biographical Information 5/2005

JOHN F. FERGUSON
Professor of Civil Engineering
University of Washington
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Seattle, WA 98195-2700
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Academic Background

Ph.D.	Stanford University	1970
M.S.C.E.	Stanford University	1964
B.S.C.E (with honors)	Stanford University	1963

Professional History

Professor, Department of Civil Engineering, University of Washington, Seattle, WA, 1979-present; Chair 1992-1997; Associate Chair 1987-1992; Acting Chair 1986-1987; Environmental Engineering and Science Program Director 1983-1987.

Visiting Scientist, Norwegian Water Research Institute, Oslo, 1979-80.

Associate Professor, Department of Civil Engineering, University of Washington, Seattle, WA, 1974-1979.

Assistant Professor, Department of Geography and Environmental Engineering, The Johns Hopkins University, Baltimore, MD, 1970-1974.

Research Fellow, Division of Engineering and Applied Physics, Harvard University, Cambridge, MA, 1969-1970.

Research Engineer, Los Angeles County Sanitation Districts, Lancaster, CA, 1964-1966

Refereed Journal Publications

Ferguson, J.F. and P.L. McCarty (1971) Effects of carbonate and magnesium on calcium phosphate precipitation, *Environ. Sci. Technol.*, Vol. 5, 434-540.

Jenkins, D., J.F. Ferguson, and A.B. Menar (1971) Chemical processes for phosphate removal, *Water Res.*, Vol. 5, 369-389.

Ferguson, J.F. and J. Gavis (1972) A review of the arsenic cycle in natural waters, *Water Res.*, Vol. 6, 1259-1274.

Gavis, J. and J.F. Ferguson (1972) The cycling of mercury through the environment, *Water Res.*, Vol. 6, 989-1008.

Ferguson, J.F., D.J. Jenkins, and J. Eastman (1973) Calcium phosphate precipitation at slightly alkaline pH values, *Jour. Water Pollution Control Fed.*, Vol. 45, 620-631.

Gavis, J. and J.F. Ferguson (1975) Kinetics of carbon dioxide uptake by phytoplankton at high pH, *Limnol. Ocean.* Vol. 20, 211-221.

Anderson, M.A., J.F. Ferguson, and J. Gavis (1976) Arsenate adsorption on amorphous aluminum hydroxide, *J. Colloid Interface Science*, Vol. 54, 391-399.

Ferguson, J.F. and T.A. King (1977) A model for phosphate removal with aluminum addition, *Jour. Water Pollution Control Fed.*, Vol. 49, 646-658.

Ferguson, J.F., G.F.P. Keay, M.S. Merrill, and A. Benedict (1979) Powdered activated carbon contact stabilization in activated sludge, *JWPCF*, Vol. 51, 2314-2323.

Eastman, J.A. and J.F. Ferguson (1981) Solubilization of particulate organic carbon during the acid phase of anaerobic digestion, *JWPCF*, Vol. 53, 352-366.

Benjamin, M.M., J.F. Ferguson, and M.E. Buggins (1981) Treatment of sulfite evaporator condensate with an anaerobic reactor, *TAPPI*, Vol. 65, 96-101.

Asplund, R., B.W. Mar, and J.F. Ferguson (1982) Total suspended solids in highway runoff in Washington State, *ASCE, JEED*, Vol. 108, 391-404.

Herrera, C.F., J.F. Ferguson, and M.M. Benjamin (1982) Evaluation of the potential for contamination of drinking water from the corrosion of tin/antimony solder, *JAWWA*, Vol. 74, 368-376.

Ferguson, J.F., B.J. Eis, and M.M. Benjamin (1983). The fate and effect of bisulfite in anaerobic treatment, *JWPCF*, Vol. 55, 1355-1365.

Benjamin, M.M., S.L. Woods, and J.F. Ferguson (1984) Toxicity and biodegradability of pulp mill waste constituents exposed to anaerobic bacteria, *Wat. Res.*, Vol. 18, 601-607.

Ferguson, J.F., B.J. Eis, and M.M. Benjamin (1984) Neutralization in anaerobic treatment of an acidic waste, *Wat. Res.*, Vol. 18, 573.

Hendrickson, K.J., M.M. Benjamin, and J.F. Ferguson (1984) Removal of silver and mercury from spent COD test solutions, *JWPCF*, Vol. 56, 468-473.

Ferguson, J.F. and L. Vrale (1984) Chemical aspects of the lime seawater process, *JWPCF*, Vol. 56, 355-363.

Nitchals, D.R., M.M. Benjamin, and J.F. Ferguson (1985) Anaerobic treatment of caustic extraction waste with sulfite evaporator condensate, *JWPCF*, Vol. 57. 253-262.

Reiber, S.H., J.F. Ferguson, and M.M. Benjamin (1987) Corrosion monitoring and control in the Pacific Northwest, *Jour. Am. Wat. Works Assoc.*, Vol. 79, No. 2, 71-74.

Stone, A., D. Spyridakis, M.Benjamin, J. Ferguson, J. Richey, and S. Osterhus (1987) The effects of short-term changes in water quality on copper and zinc corrosion rates, *Jour. Am. Wat. Works Assoc.*, Vol. 79, No. 2, 75-82.

Schultz, M., M.M. Benjamin, and J.F. Ferguson (1987) Adsorption and desorption of metals on ferrihydrite, *Environ. Sci. Technol.*, Vol. 21, 863-869.

Woods, S.L., J.F. Ferguson, and M.M. Benjamin (1988) Characterization of chlorophenol and chloromethoxybenzene biodegradation during anaerobic treatment, *Environ. Sci. Technol.*, Vol. 23, 62-68.

Reiber, S., J.F. Ferguson, and M.M. Benjamin (1988) An improved method for corrosion rate measurement by weight loss, *J. Am. Water Works Assoc.*, Vol. 80, No. 11, 41-46.

Nordqvist, K.R., M.M. Benjamin, and J.F. Ferguson (1988) Effects of cyanide and polyphosphates on adsorption of metals from simulated and real metal plating wastes, *Water Research*, Vol. 22, 837-846.

Puhakka, J.A., J.F. Ferguson, M.M. Benjamin, M. Salkinoja-Salonen (1989) Sulfur reduction and inhibition in anaerobic treatment of simulated pulp mill wastewater, *Systematic and Applied Microbiology*, Vol 11, 202-206.

Puhakka, J.A., M.M. Benjamin, J.F. Ferguson, and M. Salkinoja-Salonen (1990) Effect of molybdate ions on methanation of simulated and natural wastewater, *Appl. Microbiol. Biotechnol.*, Vol. 32, 494-498.

Puhakka, J.A., M. Salkinoja-Salonen, J.F. Ferguson, and M.M. Benjamin (1990) Carbon flow in acetoclastic enrichment cultures from pulp mill effluent treatment, *Water Research*, Vol 24, 505-519.

Paulson, A.J., M.M. Benjamin, and J.F. Ferguson (1990) Zn solubility in low carbonate solution, *Water Research*, Vol. 23, 1563-1569.

Banerjee, S., J.J. Horng, J.F. Ferguson (1991) Field Experience with Electrokinetics at a Superfund Site, Transporation Research Record, 1312, 167-174

Labib, F., J.F. Ferguson, M.M. Benjamin, M. Merigh, and N.L. Ricker (1992) Anaerobic butyrate degradation in a fluidized bed reactor: The effects of increased concentrations of H_2 and acetate, *Environ. Sci. Technol.*, Vol. 26, 369-376.

Wang, S-H., J.F. Ferguson, and J.L. McCarthy (1992) The decolorization and dechlorination of kraft bleach plant effluent solutes by use of three fungi: *Ganaderma lacidum, Coriolus versicolor* and *Hericium erinaceum, Holzforschung,* Vol. 46, 219-223.

Labib, F., J.F. Ferguson, M.M. Benjamin, M. Merigh, N.L., and N.L. Ricker (1993) Mathematical modeling of an anaerobic butyrate degrading consortia: Predicting their response to organic overloads, *Environ. Sci. Technol.,* Vol. 27, No. 13, 1673-2884.

Edwards, M. and J.F. Ferguson (1993) Accelerated testing of copper corrosion, *J. Amer. Water Works Assoc.*, Vol. 85, No. 10, 105-113.

Long, J.L., H.D. Stensel, J.F. Ferguson, S.E. Strand, J.E. Ongerth (1993) Anaerobic and aerobic treatment of chlorinated aliphatic compounds, *Jour. Environ. Engineering*, Vol 119, 303-320.

Makinen, P.M., T.J. Theno, J.F. Ferguson, J.E. Ongerth, and J.A. Puhakka (1993) Chlorophenol toxicity removal and monitoring in aerobic treatment recovery from process upsets, *Environ. Sci. Technol.*, Vol 27, 1434-1439.

Wang, S.-H., J.L. McCarthy, and J.F. Ferguson (1993) Utilization of glucososaccharinic acid and components of kraft black liquor as energy sources for growth of anaerobic bacteria, *Holzforschung*, Vol. 47, 141-148.

Perkins, P.S., S.J. Komisar, J.A. Puhakka, and J.F. Ferguson (1994) Effects of electron donors and metabolic inhibitors on reductive dechlorination of 2,4,6-trichlorophenol, *Water Research*, Vol. 28, No. 10, 2101-2107.

Ryding, J.M., J.A. Puhakka, J.F. Ferguson, and S.E. Strand (1994) Degradation of chlorinated phenols by a toluene enriched microbiol culture, *Water Research*, Vol 28, No. 9, 1897-1906.

Ofjord, G.D., J.A. Puhakka, and J.F. Ferguson (1994) Reductive dechlorination of Aroclor 1254 by marine sediment cultures, *Environ. Sci. Technol.*, Vol 25, No. 13, 2286-2294.

Edwards, M., J.F. Ferguson, and S.H. Reiber (1994) The pitting corrosion of copper, *JAWWA*, Vol. 86, No. 7, 74-90.

Puhakka, J.A., R.P. Herwig, P.M. Koro, G.V. Wolfe, and J.F. Ferguson (1995) Biodegradation of chlorophenols by mixed and pure cultures from a fluidized-bed reactor, *Appl. Microbiol. Biotechnol.,*Vol. 42, 951-957.

Sletten, R.S., M.M. Benjamin, J.J. Horng, and J.F. Ferguson (1995) Physical-chemical treatment of landfill leachate for metals removal, *Water Research*, Vol. 29, No. 10, 2376-2386.

Porter, R.L. and J.F. Ferguson (1995) Improved monitoring of corrosion processes, *JAWWA*, Vol. 87, No. 11, 85-95.

Männistö, M.K., E.S. Melin, J.A. Puhakka, and J.F. Ferguson (1996) Biodegradation of PAH mixtures by a marine sediment enrichment, *Jour. Polycyclic Aromatic Hydrocarbons*, Vol. 11, 27-34.

Chen, C., J.A. Puhakka, and J.F. Ferguson (1996) Transformation of 1,1,2,2-tetrachloroethane under methanogenic conditions, *Environ. Sci. Technol.*, Vol. 30, No. 2, 542-547.

Korshin, G.V., S.A.L. Perry, M.A. Edwards, and J.F. Ferguson (1996) The influence of natural organic matter on corrosion of copper in potable water, *JAWWA*, Vol. 88, No. 7, 36-47.

Melin, E.S., J.A. Puhakka, S.E. Strand, K.J. Rockne, and J.F. Ferguson (1996) Fluidized-bed enrichment of marine ammonia-to-nitrite oxidizer and their ability to cometabolically oxidize chloroaliphatics, *Int. Biodet. Biodegrad..,*Vol 38, No. 1, 9-18.

Melin, E.S., J.F. Ferguson, J.A. Puhakka, (1997) Pentachlorophenol biodegradation kinetics of an oligotrophic fluidized-bed enrichment culture, *Appl. Microbiol. Biotechnol*. 47, 675.

Ballapragada, B.S., H.D. Stensel, J.A. Puhakka, J.F. Ferguson (1997) Effect of hydrogen on reductive dechlorination of chlorinated ethenes, *Environ. Sci. Technol*. 31, 1728-1734.

Melin, E.S., J.A. Puhakka, J.F. Ferguson, (1998) Enrichment and operation strategies for polychlorophenol degrading microbial cultures in an aerobic fluidized-bed reactor, *Wat. Environ. Res*., 70(2), 171-180.

Ward, A., H.D. Stensel, J.F. Ferguson, G. Ma, S. Hummel (1998) Effect of autothermal treatment on anaerobic digestion in the dual digestion process. *Wat. Sci. Tech*. 38, 435-442

Mohn, H., J.A. Puhakka, J.F. Ferguson (1999) Effects of electron donors on degradation of pentachlorophenol in a methanogenic fluidized bed reactor. *Environmental Technology*, 20:909-920.

Zou, S., K.M. Anders, J.F. Ferguson (1999) Pentachlorophenol dechlorination in fluidized bed reactors under methanogenic conditions. *Bioremediation Journal*, 3(2): 93-104

Korshin, G.V., J.F. Ferguson, A.N. Lancaster (1999) Influence of natural organic matter on the corrosion of leaded brass in potable water. *Corrosion Science,* 42(1), 53-62.

Magar, V.S., H.D. Stensel, J.A. Puhakka, J.F. Ferguson (1999) Sequential anaerobic dechlorination of pentachlorophenol: Competitive inhibition effects and a kinetic model. *Environ. Sci. Technol.* 33, 1604-1611.

Chen, C., B.S. Ballapragada, J.A. Puhakka, S.E. Strand, and J.F. Ferguson (1999) Anaerobic transformation of 1,1,1-trichloroethane by municipal digester sludge. *Biodegradation*, 10, 297-305.

Zou, S., K.M. Anders, J.F. Ferguson (2000) Biostimulation and bioaugmentation of anaerobic pentachlorophenol degradation in contaminated soils. *Bioremediation Journal*, 4(1), 19-25.

Ferguson, J.F. and J.M.H. Pietari, (2000) Anaerobic transformations and bioremediation of chlorinated solvents, *Environmental Pollution, 107, 209-215* .

Zou, S., H.D. Stensel, J.F. Ferguson (2000) Carbon tetrachloride degradation: Effect of microbial growth substrate and vitamin B_{12} content. *Environ. Sci. Technol.* 34(9), 1751-1757.

Magar, V.S., H.D. Stensel, J. Puhakka, J.F. Ferguson (2000) Characterization studies of an anaerobic, pentachlorophenol-dechlorinating enrichment culture. *Bioremediation Journal,* 4(4), 285-293.

Moen, G., H.D. Stensel, R. Lepistö, J.F. Ferguson (2003) Effects of solids retention time on the performance of thermophilic and mesophilic digestion of combined municipal wastewater sludges, *Water Environment Research,* 75(6), 539-548.

Korshin, G.V., J.F. Ferguson, A.N. Lancaster (2005) Influence of natural organic matter on the morphology of corroding surfaces of lead surfaces and behavior of lead-containing particles, *Water Research,* 39, 811-818.

Pietari, J.M.H., Herwig, R.P. and J.F. Ferguson, Characterization of a psychrotrophic, anaerobic tetrachloroethene and trichloroethene dechlorinating enrichment, submitted to *Environ. Sci. Technol.*

Pietari, J.M.H., Herwig, R.P. and J.F. Ferguson, Isolation and characterization of a PCE to cDCE dechlorinating strain JPD-1, manuscript in preparation (pending replication of DNA sequencing).

Conklin, A.S., Bucher, R.H., Stensel, H.D. and J.F. Ferguson, Oxygen inhibition and toxicity in anaerobic sludge digestion, submitted *Water Environ. Research*.

Conklin, A, Stensel, HD, and JF Ferguson (2005) The growth kinetics and competition between *Methanosarcina* and *Methanosaeta* in mesophilic anaerobic digestion, submitted *Water Environ. Research.*

Fully-Refereed Conference Proceedings

Ferguson, J.F and R..L. Horres (1979) Two-step precipitation of calcium phosphates, *Progress Water Technology*, Suppl. 1, 157-170.

Damhaug, T., J.F. Ferguson, H. Buset, and R. Brusletto (1981) Control of alum addition in wastewater treatment, *Wat. Sci. Tech.,* Munich, 531-537.

Brown, C.A., K.E. Kiernan, J.F. Ferguson, and M.M. Benjamin (1984) Treatability of recreational vehicle wastewater in septic systems at highway rest areas, *Transportation Research Record,* Vol 995, 1-11.

Hakulinen, R., S. Woods, J.F. Ferguson, and M.M. Benjamin (1985) The role of facultative anaerobic microorganisms in anaerobic biodegradation of chlorophenols, *Wat. Sci. Tech.,* Vol. 17, 289-301.

Ferguson, J.F. and M.M. Benjamin (1985) Studies of anaerobic treatment of sulfite process wastes, *Wat. Sci. Tech.,* Vol. 17, 113-121.

Qiu, R., J.F. Ferguson, and M.M. Benjamin (1987) Sequential anaerobic and aerobic treatment of Kraft pulping wastes, *Wat. Sci. Tech.* 19,

Ferguson, J.F. and E. (Jonsson) Dalentoft (1991) Investigation of anaerobic removal and degradation of organic chlorine from Kraft bleaching wastewaters, *Wat. Sci. Tech.,* Vol 24, 241-250

Rasmussen, G., S.J. Komisar, J.F. Ferguson, (1992) Transformation of Tetrachloroethane to Ethene in Mixed Methanogenic Cultures: Effect of Electron Donor, Biomass Levels, and Inhibition, in **Bioremediation of Chlorinated and Polycyclic Aromatic Hydrocarbon Compounds**, R.E. Hinchee, et al., eds. Lewis Publishers, p. 309-313.

Puhakka, J.A., P.M. Makinen, M. Lundin, and J.F. Ferguson (1993) Aerobic and anaerobic biotransformation and treatment of chlorinated pulp bleach waste constituents, *Wat. Sci. Tech.,* Vol. 29, No. 5-6, 73-80.

Ferguson, J.F. (1994) Anaerobic and aerobic treatment for AOX removal, *Wat. Sci, Tech.,* Vol. 29, No. 5-6, f149-162.

Melin, E.S., J.A. Puhakka, M. Mannisto, and J.F. Ferguson (1995) Degradation of polycyclic aromatic hydrocarbons by a marine fluidized-bed enrichment, in **Biological Unit Processes for Hazardous Waste Treatment**, Vol. 9 of *Proceedings of 3rd International Symposium on In Situ and On-Site Bioreclamation,* Hinchee, Skeen and Sayles, eds., Battelle Press, Columbus, OH, 325-330.

Magar, V.S., H. Mohn, J.A. Puhakka, H.D. Stensel, and J.F. Ferguson (1995) Reductive dechlorination of pentachlorophenol by enrichments from municipal digester sludge, in **Bioremediation of Chlorinated Solvents**, Vol. 4 of *Proceedings of 3rd International Symposium on In Situ and On-Site Bioreclamation,* Hinchee, Leeson and Semprini, eds., Battelle Press, Columbus, OH, 77-83.

Ballapragada, B.S., J.A. Puhakka, H.D. Stensel, and J.F. Ferguson (1995) Development of tetrachloroethene transforming anaerobic cultures from municipal digester sludge, in **Bioremediation of Chlorinated Solvents**, Vol. 4 of *Proceedings of 3rd International symposium on In Situ and On-Site Bioreclamation,* Hinchee, Leeson and Semprine, eds, Battelle Press, Columbus, OH.

Puhakka, J.A., E.S. Melin, K.T. Jarvinen, P.M. Koro, J.A. Rintala, P. Makinen, W.K. Shieh, and J.F. Ferguson (1995) Fluidized-bed biofilms for chlorophenol mineralization, *Wat. Sci. Tech..,* Vol. 31, No. 1, 227-235.

Korshin, G.V., J.F. Ferguson, A. Lancaster, H. Wu (1997) Influence of Humic Substances on the Corrosion of Copper- and Lead-Containing Materials in Potable Water, in *The Role of Humic Substances in the Ecosystems and in Environmental Protection,* Drozd, Gonet, Senesi, Weber, eds., International Humic Substances Society, Wroclaw, Poland.

A. S. Conklin, J. D. Zahller, R. H. Bucher, H. D. Stensel and J. F. Ferguson (2004) Acetoclastic and Hydrolytic Activity in Anaerobic Digestion – Keys to Process Stability, Anaerobic Digestion 2004, 10th World Congress, Montreal, August.

A. J. Straub, A. C. Conklin, J. F. Ferguson, H. D. Stensel (2005) Use of the ADM1 to investigate the effects on mesophilic digester stability of acetoclastic methanogens population dynamics. The First International Workshop on the IWA Anaerobic Digestion Model No. 1, 4-6 September 2005, Lyngby, Denmark

Abstract and Non-Refereed Conference Proceedings and Other Non-Journal Articles (incomplete listing)

Ferguson, J.F., D. Jenkins, and W. Stumm (1971) Calcium phosphate precipitation in wastewater treatment, in *Water 1970 Chem. Engr. Prog. Symposium Series,* Vol. 67, 107.

Ferguson, J.F. and D. Simmons (1975) The fate of nitrogen and phosphorus in Back River sub-estuary, in *Waste Treatment Studies*, Chesapeake Research Consortium, Baltimore.

Gavis, J.W. Pasciak, and J.F. Ferguson (1975) Diffusion transport and kinetics of nutrient uptake by phytoplankton, (abstract), ACS National Meeting.

Ferguson, J.F. and D.N. Given (1976) Chemical precipitation in water softening and iron and manganese removal, *Proceedings, 18th Annual Public Water Supply Engineers' Conference,* University of Illinois, 5-24.

Ferguson, J.F., G.F.P. Keay, M.S. Merrill, and A.H. Benedict (1976) Powdered activated carbon-biological treatment: Low detention time process, *Proceedings 31st Purdue Industrial Waste Conference*, 468-478.

Spencer, R., A. J. Shuckrow, and J.F. Ferguson (1976) The addition of powdered activated carbon to anaerobic digestors effects on methane production, *Extended Abstracts for ASCE-EED National Meeting,* Seattle.

Woods, S.L., J.F. Ferguson, and M.M. Benjamin (1981) Assessing the toxicity of sulfite evaporator condensate to methanogens, *Proceedings ASCE Water Forum-81,* San Francisco.

Ferguson, J.F. (1985) Anaerobic treatment of pulping and bleaching waste streams, *Proc. AICHE 1985 National Meeting*, presented August, 1985, Seattle, WA.

Jurgensen, S.L., M.M. Benjamin, and J.F. Ferguson (1985) Treatability of thermomechanical pulping process effluent with anaerobic biological reactors, *Proc. 1985 TAPPI Environmental Conference,* presented April, 1985, Mobile, AL.

Ferguson, J.F. (1986) Plumbing materials and water quality deterioration in *Water Quality Concerns in the Distribution System,* AWWA Proceedings, Denver, CO.

Labib, F., J.F. Ferguson, and M.M. Benjamin (1988) The response of a butyrate fed anaerobic fluidized bed reactor to transient loading, *Proc. 43rd Purdue Industrial Waste Conference,* Lewis Publishers, 363-371.

Ferguson, J.F., Luonsi, A., and D. Ritter (1990) Sequential anaerobic/aerobic biological treatment of bleaching wastewaters, *Proc. TAPPI Environmental Conference,* Seattle, April, 1990, 333-338.

Rumpf, M. I. and J.F. Ferguson (1990) Anaerobic pretreatment of a landfill leachate for metals and organics removal, *Proc. 1990 ASCE Envir. Engr. Specialty Conference,* Washington, D.C., 552-559.

Leif, W., J.F. Ferguson, and M.M. Benjamin (1990) Assessing the corrosion of lead tin solder (abstract), *AWWA Water Quality Technology Conference,* San Diego, November.

Hodges, L.M., S.J. Komisar, H.D. Stensel, J.F. Ferguson (1990) Volatile organic degradation in fermentation reactors. *Proc. 63rd Annual Conference of the Water Pollution Control Federation*, Wash. D.C.

Ferguson, J.F., E. Tuomi, and H.D. Stensel (1991) Advanced biological treatment for groundwater contaminants: Development of specialized aerobic consortia, *Proceedings Paper, Air and Waste Management Association*, Vancouver.

LaFond, R.A. and J.F. Ferguson (1991) Anaerobic and aerobic biological processes for removal of chlorinated organics from Kraft bleaching wastes, *Proc. TAPPI Environmental Conference,* San Antonio, 797-805.

Ferguson, J.F. (1993) Anaerobic and aerobic treatment for AOX removal, *Proc. TAPPI-1993 Environmental Conference,* 857-864.

Ferguson, J.F., G.V. Korshin, S.A.L. Perry, and B. Faris, (1993) Evaluation of water quality effects on corrosion of copper and lead-tin solder in Portland water, *Proc. 1993 Water Quality Technology Conference,AWWA,* Miami, FL, 1481-1499.

Ofjord, G.D., J. Lee, JA. Puhakka, R.P. Herwig, and J.F. Ferguson (1993) Dechlorination of Pentachlorophenol and polychlorinated biphenyls by marine sediment enrichments, *Proc. IAWAQ Specialized Conference on Aquatic Sediments,* Milwaukee, WI.

Ballapragada, B.S., V.S. Magar, J.A. Puhakka, H.D. Stensel, and J.F. Ferguson (1994) Fate and biotransformation of tetrachloroethene and pentachlorophenol in anaerobic digesters, *Proc. 1994 Wat. Environ. Fed. Annual Conference,* Chicago.

Korshin, G.V. and J. F. Ferguson (1996) Effects of natural organic matter on corrosion of copper and lead-containing brass in potable waters, *Proc. Intl. Workshop on Internal Corrosion in Water Distribution Systems,* Gothenburg, Sweden.

Hinck, M.L., J.A. Puhakka, J.F. Ferguson (1996) Resistance of EDTA and DTPA to Aerobic and Anaerobic Biodegradation, *Proc. 5th IAWQ Symposium on Forest Industry Wastewaters, Vancouver, B.C.*

Ferguson, J.F., S.H. Reiber, G.V. Korshin, R.L. Porter, and M.A. Edwards (1996) Development in pipe coupon monitoring techniques for corrosion control studies, *Proc. Intl. Workshop on Internal Corrosion in Water Distribution Systems,* Gothenburg, Sweden.

Boyle, M.F., B.S. Ballapragada, H.D. Stensel, J.F. Ferguson (1997) Chloroethene dechlorination kinetics of enrichments developed under different loading conditions, *Proc. Fourth Int'l In Situ and On-Site Bioremediation Symposium,* New Orleans.

Zou, S, K.M. Anders, J.F. Ferguson (1997) Biostimulation and bioaugmentation of anaerobic pentachlorophenol degradation, *Proc. Fourth Int'l In Situ and On-Site Bioremediation Symposium,* New Orleans.

Korshin, G.V., J.F. Ferguson (1997) Effects of Ozonation and Chlorination of NOM on Corrosion of Lead and Copper. AWWA Annual Conference, Atlanta.

Ward, A, H.D. Stensel, J.F. Ferguson, G. Ma, S. Hummel (1997) Preventing growth of pathogens in post-pasteurized biosolids, *Proc.WEF Annual Conf.*, Chicago.

Maco, R. S., H.D. Stensel, J.F. Ferguson (1998) Impacts of solids recycling strategies on anaerobic digester performance, *Proc. WEF Annual Conf.*, Orlando FL, [Vol. 2, pp. 213-230]

Zou, S., H.D. Stensel, J.F. Ferguson (1998) Biological treatment of carbon tetrachloride in soil vapor extraction contaminated gases, Vol. 2 of *Proceedings of the International Conference on Decommissioning and Decontamination and on Nuclear and Hazardous Waste Management,* American Nuclear Society, Denver, CO. pp 1045-1050.

Pietari, J.M.H., J.F. Ferguson (1999) Characterization of a psychrophilic TCE-dechlorinating culture and comparison with a mesophilic dechlorinating culture. In Situ and On-Site Bioremediation Symposium, San Diego, April.

Pietari, J.M.H., R.P. Herwig, J.L. McLarnan, J.F. Ferguson (1999) Characterization of an anaerobic PCE or TCE to cis-1,2-DCE dechlorinating psychrotrophic enrichment. American Soc. Microbiol. Annual Meeting, Chicago, May.

Ferguson, J.F., G.V. Korshin (1999) Effects of humic substances on drinking water quality. *Proc. 4th Finnish Conference of Environ. Sciences,* Tampere, Finland. May

Elardo, P., Danowski, P., J. Ferguson (1999) Options for treating stormwater runoff from wood-preserving facilities, *Industrial Wastewater*, Nov/Dec 1999, pp 34-39.

Bucher, B., G. Newman, R. Moore, R. Lepisto, H.D. Stensel, J.F. Ferguson (2001) Pilot Plant Investigation of Thermophilic-Mesophilic Digestion for a Full-Scale Retrofit, Biosolids 2001, Proceedings Joint WEF/AWWA Biosolids and Plant Residuals Conference, San Diego, February (13)

Moen, G., Stensel, H.D., Lepisto, R., J.F. Ferguson (2001) Effect of Solids Retention Time on the Performance of Thermophilic and Mesophilic Digestion, WEFTEC, October.

J.M.H. Pietari, R.P. Herwig, J.F. Ferguson (2001) Characterization of tetrachloroethene and cis-1,2-dichloroethene dechlorinating cultures with terminal restriction fragment length polymorphism (T-RFLP) analysis, In situ and On-site Biormediation, 6th International Symposium, San Diego.June.

J.M.H. Pietari, R.P. Herwig, J.F. Ferguson (2002) Characterization of a microaerophilic and psychrotrophic, tetrachloroethene to cis-1,2-dichloroethene dechlorinating bacterium, Strain JPD-1, American Society of Microbiology National Meeting, Salt Lake City, UT, May.

Satterberg, J.M., Herwig, R.P., and J.F. Ferguson (2003) Dehalogenation of tetrachlorethylene in estuarine sediment enrichments: characterization of the dechlorinating microbial community and effect of sulfate reduction inhibition. NIEHS Superfund Basic Research Program Annual Meeting, Dartmouth, NH, November

Conklin, A.S., Bucher, R.H., Stensel, H.D. and J.F. Ferguson (2004) Oxygen inhibition and toxicity in anaerobic sludge digestion, Water Environment Federation Biosolids Specialty Conference, Salt Lake City, UT, February.

Conklin, A.S., Zahller, J.D., Bucher, R.H., Stensel, H.D., and J.F. Ferguson (2004) Acetoclastic and hydrolytic activity in anaerobic digestion—keys to process stability, Anaerobic Digestion 2004, International Water Association Specialty Conference, Montreal, Quebec, August. (Vol. 2, pp 833-838).

Bouwman, R., Langwaldt, J.H., J.F. Ferguson, R. Lepistö (2004) Toxicity and biodegradation of long chain fatty acids in thermophilic anaerobic sludge, Anaerobic Digestion 2004, International Water Association Specialty Conference, Montreal, Quebec, August.

Bucher, RH, Zahller, JD, Conklin, AS, Ferguson, JF and HD Stensel (2004) Evaluation and Modeling of Staged Anaerobic Digestion, Anaerobic Digestion 2004, International Water Association Specialty Conference, Montreal, Quebec, August

Conklin, A., Stensel, HD, and JF Ferguson, The growth kinetics and competition between *Methanosarcina* and *Methanosaeta* in mesophilic anaerobic digestion, accepted for presentation at WEFTEC, October 2005, Washington DC

Conklin, A, Zahller, J, Stensel, HD, and JF Ferguson, Development of a tool to monitor anaerobic digester stability and capacity and its application to full-scale digesters, accepted for presentation at WEFTEC, October 2005, Washington DC

Books, Chapters

Jenkins, D., V. Snoeyink, J.F. Ferguson, and J. Leckie (1971) Water Chemistry Laboratory Manual, Assoc. of Environmental Engineering Professors, 1971 (revised 1973, 1980), publisher in 1980 John Wiley and Sons.

Jenkins, D., A.B. Menar, and J.F. Ferguson (1973) Recent studies of calcium phosphate-precipitation in wastewaters, in **Applications of New Concepts of Physical-Chemical Wastewater Treatment, Progress in Water Technology**, Vol. 1, Pergamon Press.

Ferguson, J.F. and M.A. Anderson (1974) Chemical forms of arsenic in water supplies and their removal, in **Chemistry of Water Supply, Treatment and Distribution**, Vol. 1, A. Rubin, ed. Ann Arbor Science Publishers, Ann Arbor.

Ferguson, J.F. (1975) Chemical precipitation modeling in sanitary engineering, in **Mathematical Modeling for Water Pollution Control Processes,** T.M. Keinath and M.P. Wanielista, eds., Ann Arbor Science Publishers, Ann Arbor.

Ferguson, J.F. (1985) Corrosion arising from low alkalinity, low hardness or high neutral salt content water, Chapter 8 in **EBI/AWWARF Project Book**, June, 1985.

Ferguson, J.F., O. Von Franque, and M.R. Schock (1996) Corrosion in copper in potable water systems, Chapter 5 in **Internal Corrosion in Water Distribution Systems,** 2nd ed., AWWARF, Denver, CO.

Ferguson, J.F., R. Ryder, E.A. Vik, and I. Wagner (1996) Mitigation of corrosion impacts, Chapter 8 in **Internal Corrosion in Water Distribution Systems**, 2nd ed., AWWARF, Denver, CO.

Reports, Discussions, and Other Scholarly Papers

Ferguson, J.F. and D. Jenkins (1973) Discussion of “Pilot Plant Tests of a Phosphate Removal Process**,”** by Levin, Topal, Tarnay and Samworth, appearing in *JWPCF*, Vol 45, 552-555.

Ferguson, J.F., G.F.P. Keay, and E.N.D. Amoo (1975) Combined PAC biological contact stabilization treatment of municipal wastewater, Report to Metro.

Ferguson, J.F. and Brown and Caldwell Engineers (1976) Comparison of powdered activated carbons for municipal wastewater treatment, Report to Amoco Corporation.

Ferguson, J.F., K.B. Parrish, D.W. Browne, S. Lellelid, and R.O. Sylvester (1977) A study of wastewater handling, holding, and disposal from Washington State ferries, *Washington State Highway Department Research Program Report*, Vol 27, 1.

Ferguson, J.F. (1979) Discussion of "Alkalinity—A Neglected Parameter" by Neilson and Bundgaard, *Prog. Water Technology*.

Horner, R.R., S.J. Burges, J.F. Ferguson, B.W. Mar, and E.B. Welch (1979) Highway runoff monitoring: The initial year, May 1977-August 1978, *Highway Runoff Water quality Research Project Report 2*, Department of Civil Engineering, University of Washington.

Vause, K.H., J.F. Ferguson, and B.W. Mar (1980) Water quality impacts associated with leachates from highway woodwaste embankments, *Highway Runoff Water Quality Research Project 4*, Department of Civil Engineering, University of Washington.

Asplund, R., J.F. Ferguson, and B.W. Mar (1980) Characterization of highway runoff in Washington State, *Highway Runoff Water Quality Research Project 6*, Department of Civil Engineering, University of Washington.

Banerjee, S., J.J. Horng, J.F. Ferguson, and P.O. Nelson (1988) Field scale feasibility study of electro-kinetic remediation, Final Report, EPA CR811762-01, August.

Reiber, S.R., M.M. Benjamin, and J.F. Ferguson (1988) Internal corrosion within the Everett distribution system, Technical Report, prepared for Department of Public Works, City of Everett, March.

Benjamin, M.M., S.H. Reiber, J.F. Ferguson, E.A. Vanderwerff, and M.W. Miller (1990) Chemistry of corrosion inhibitors in potable water, AWWARF report.

Ferguson, J.F. (1993) *Anaerobic and Aerobic Biological Treatment of Bleaching Effluents to Remove Chlorinated Organics*, The Chlorine Institute, Washington, D.C.

Edwards, M., T.E. Meyer, J. Rehring, J. Ferguson, G. Korshin, and S. Perry (1996) Role of inorganic anions, NOM, and water treatment processes in copper corrosion, *American Water Works Research Foundation*, Denver, CO, 152 pp.

Ferguson, J.F. (1996) Have we bitten off more than we can chew, or is environmental engineering more than we thought it was? Water Environment Research, 68:3, 259.

Ferguson, J.F. (1997) The system is the thing, Water Environment Research 69:6, 1065.

Korshin, G.V., J.F. Ferguson, A.N. Lancaster and H. Wu (1999) Corrosion and Metal Release for Lead Containing Materials: Influence of Natural Organic Matter and Corrosion Mitigation, AWWARF report, Denver, CO. 176 pp.

Ballapragada, B.S., Stensel, H.D., J.F. Ferguson, V.S. Magar, J.A. Puhakka (1998) Toxic Chlorinated Compounds: Fate and Biodegradation in Anaerobic Digestion, Water Environ. Res. Foundation, Project 91-TFT-3

Newton, C.D., H.D. Stensel, J.F. Ferguson, (1999) Discussion of "A systematic artifact that significantly influences anaerobic digestion efficiency measurement, by S.S. Beall, D. Jenkins, S.A. Vidanage, *Wat. Environ. Res.* 71, 1257-58.

Borton, D., Ferguson, J., Fisher, R., Hall, E., Hall T., Joutijarvi, T., Luonsi, A. Munkittrick, K., and M. Priha (2004) 2003 IWA Symposium and Fate and Effects Conference, Paperi ja Puu, 86:5, 346-348.

Ferguson, JF (2004) Engineering Controls for Ballast Water Discharge: Developing Research Needs, Report of an NSF-sponsored workshop.

Sponsored Research since 1985

Funded (current funding in bold)

8/85-6/88	Treatment of Waste Contaminated Ground by Electro-Kinetics (Co-PI, Banerjee), EPA, $255,000.
9/85-3/88	Chemistry and Application of Corrosion Inhibitors in Potable Water (Co-PI, Benjamin), AWWA Research Foundation, $120,000.
6/85-11/88	Transient Response Studies and On-Line Control in Anaerobic Wastewater Treatment Reactors (Co-PI, Benjamin and Ricker), NSF, $330,000.
1984-1990	Monitoring Water Quality (Co-PIs, Benjamin, Spyridakis), EPA, $350,000.
11/86-12/87	TFSC Model Development and Technical Assistance (Co-PI, Stensel, Benjamin), Metro, $89,000.
5/87-10/87	Corrosion Evaluation in the Everett Water Supply System (Co-PI, Benjamin), City of Everett, $34,000.
6/87-11/87	Evaluation of Dellchem Treatment at Tacoma North End (Co-PI, Stensel), WA Dept. of Ecology, $35,000.
5/88-9/89	Evaluation of Pretreatment for Discharge of Cedar Hills Leachate to the Metro Sewer System (Co-PI, Benjamin), King County (as subcontract to QGNF Co), $207,000.
8/88-7-90	Toxics Biodegradation in Municipal Wastewater Treating Using Fermentation, Anoxic and Anaerobic Process Modifications (Co-PI, Stensel), EPA, $239,000.
10/89-10/93	Advanced Biological Treatment Technology to Reduce Health Risk of Halogenated Organic Contaminants (Co-PIs, Stensel, Strand, Herwig), NIEHS, $1,020,000;
4/92-4/95	$900,000;
4/95-4/00	$1,000,000
4/00-4/06	currently $183,000 per year
6/90-7/92	Advanced Biological Treatment of Bleaching Wastes, The Chlorine Institute, $208,000.

6/91-6/94	Biodegradation of Polychlorinated Biphenyls and Polycyclic Aromatic Hydrocarbons in Contaminated Marine Sediments (Co-PIs, Staley, Herwig), Office of Naval Research, $375,000.
9/92-9/94	The Role of Inorganic Anions and Natural Organic Matter in the Corrosion of Copper Pipe (Co-PI, Marc Edwards, U. CO), AWWARF, $200,000.
3/92-3/95	Dehalogenation of Organic Pollutants in Anaerobic Digestion (Co-PI, Stensel), METRO, $125,000, WERF, $362,000.
4/92-4/96	Bioremediation of Marine Sediments (Co-PI, Stensel), Office of Naval Research, $210,000.
9/94-9/96	Corrosion and Metal Release for Lead-Containing Materials: Influence of Natural Organic Matter and Corrosion Mitigation, AWWARF, $200,000.
10/94-9/04	Graduate Fellowships and Advanced Wastewater Research, (Co-PI, Stensel) King Co. Department of Natural Resources, currently $101,000 per year
3/95-7/01	Tools for Evaluating the Effects of Subsurface Restoration Technologies on Uncertainty and Risk Reduction, subproject of Consortium for Risk Evaluation with Stakeholder Participation, (Co-PI, Stensel, Massmann) U.S. Dept. of Energy, $150,000 per year.
6/96-6/97	Pentachlorophenol Treatment Alternatives, Western Wood Preservers Institute, $25,000.
12/00-12/03	Post Optimization Lead and Copper Control Monitoring Strategies, AWWARF #2679, (Co-Investigator, with Korshin [G. Kirmeyer of Economic & Engineering Services, Inc. is PI]) $400,000 total project.
10/01-9/02	RM-03 Control of Contaminant Migration, CRESP, Department of Energy, $71,422, PI.
6/02-9/05	Tank Waste Initiative, CRESP, Department of Energy, $89,000, UW budget supporting my activities (with Korshin)
3/03-2/04	Engineering Controls for Ballast Water Discharges: A Workshop to Develop Research Needs, NSF, $84,000.
10/03-9/06	Acetoclastic and Hydrolytic Activity in Anaerobic Digestion—Keys to Process Stability and Process Control, NSF, $505,000. (PI with Stensel and Stahl).
5/05-4/08	Fundamental Mechanisms of Lead Oxidation: Effects of Chlorine, Chloramine and Natural Organic Matter on Lead Release in Drinking Water, NSF, $477,011. (Co-PI with Korshin)

Project Reports (reports to sponsors)

Some, not all, are listed in “Reports, Discussions, Other Scholarly Publications” above

Invited Lectures and Seminars, last 10 years

Lecture at Duke University, 1988.

Seminar on Bleaching and the Environment, Pacific Northwest TAPPI, Seattle, WA, 1988.

Paper presented at American Society of Microbiology Northwest Meeting, Seattle, WA, 1989.

Berg Lecture, Department of Civil Engineering, University of Washington, 1990.

Lecture at Workshop on Corrosion Monitoring and Control, Oslo, Norway, 1990.

Lecture at University of Aalborg, Denmark, 1990.

Lecture at Purdue University, 1990.

Paper presented at TAPPI Environmental meeting, Seattle, WA, 1990

Lecture to Department of Ecology engineers, Redmond, WA, 1990.

Position paper presented at National Conference on Environmental Engineering Education, Corvallis, 1991

Lecture at Wastewater Technology Centre, Hamilton, Ontario, 1992

Speaker at EPA Workshop on Lead and Copper Rule, Chicago, IL, 1992

Lectures on Anaerobic Treatment of Forest Industry Wastewaters at Nanjing Forestry University, Nanjing, China April, 1992

AWWA Conference on Lead and Copper Rule, Seattle, WA, 1993.

Speaker at Oregon Graduate Institute seminar, 1994

Lectures on Anaerobic Treatment of Industrial Wastewaters at Chengdu University of Science and Technology, Chengdu, China April, 1994

Speaker at WERF Symposium, Miami Beach, FL, 1995.

Biological Dehalogenation in Marine Sediments, ONR Workshop, Bethesda, MD, 1996

Applied Microbiology: Anaerobic Processes, CRESP Symposium, Seattle, WA, 1996

Invited speaker, Nessling Symposium on Bioremediation, Helsinki, Finland, 1998

Invited speaker, 4th Finnish Conference of Environmental Sciences, Tampere, Finland, 1999

Presented Doctoral Course on Advances in Biological Wastewater Treatment at Tampere University of Technology, Tampere, Finland, May, 1999

Speaker at Civil Engineering Departmental Seminar, University of Minnesota, April, 2001

Presentations Given at Conferences, last 10 years

3rd IAWPRC Symposium on Forest Industry Wastewaters, Tampere, Finland, 1990.

AWWA Water Quality Technology Conference, San Diego, 1990.

TAPPI Environmental Conference, San Antonio, TX, 1991.

Air and Waste Management Association Conference, Vancouver, B.C., 1991.

TAPPI Environmental Conference, Boston, MA, 1993.

4th IAWQ Conference on Forest Industry Wastewater, Tampere, Finland, 1993.

AWWA Annual Conference, Atlanta, 1997

12th Annual WEF Residuals and Biosolids Management Conference, Bellevue, 1998

WEF Annual Conference, Orlando, 1998

Professional Society Membership

American Association for the Advancement of Science, since 1966
American Chemical Society, 1970-1980
Association of Environmental and Science Engineering Professors, since 1971
American Society of Civil Engineers, since 1963
American Society of Limnology and Oceanography, 1969-1980
American Water Works Association, since 1975
International Water Association, since 1990
TAPPI (Technical Association of the Pulp and Paper Industry), since 1980
Water Environment Federation, since 1966

Professional Society and Other Service

AWWA Student Activities Committee, 1974-1977, Member Control Group, 1980-82
AEEP Distinguished Lecturer Committee, 1974-78, Chair 1978
WPCF Water Reuse Committee, 1974
Program Committee, ASCE-EED National Conference, Chairman, 1975-76
ASCE-EED Sessions Committee, 1976-77
AEEP Board of Directors, 1978-81
ASCE-EED Publications Committee, Acting Editor, Jour. Environ. Engr. Div., 1978-82
WPCF Awards Committee - H.P. Eddy Award, 1978-82, '84-87, Chair, 1987
WPCF Program Committee - Research Symposium Subcommittee, 1978-82
AWWA Corrosion and Stability Research Committee, Chairman, 1980-84, Member 1985-1992
AWWA/Engler Bunte Joint Committee on Corrosion in Water Systems, 1983-86, '92-95
Scientific Programme Committee, IAWPRC Symposium on Forest Industry Wastewater, 1989-90, 91-92, 95-96, 99.
Chair, Remediation of Solvents in Subsurface Environments Research Symposium, NIEHS, 1996
Management Group, IWA Specialty Group on Forest Industry Wastewaters, 1990-present
6th National Conference on Environ. Engr. Education, Steering Committee1990-93
TAPPI Water Quality Committee, 1991-1995
AWWA Research Division Board of Trustees, 1992-present, Vice-Chair, 1995-97, Chair, 1998-2001, Technical and Educational Council, member 1998-2001.
Editorial Board of Review for *Water Environment Research*, 1995-1999
Chair, Organizing and Program Committees, 7th IWA Symposium on Forest Industry Wastewaters, June 2003, Seattle,WA
Member, ScientificCommittee, 8th IWA Symposium on Forest Industry Wastewaters, April 2006, Vitoria, Brazil
Review panel, NIEHS Superfund Basic Research Program program projects, September, 2004
Participant, Technical Workshop on Ballast Water Management for Vessels Declaring No Ballast Onboard, U.S. Coast Guard, Cleveland, May, 2005
Participant, Evaluating Ballast Water Treatment Systems Onboard Ships, Pacific Marine Fisheries Commission, Portland, June, 2005
Review panel, NSF IGERT preproposal (BES program), April 2004, Washington DC

Reviews Made--typical for last 10 years

Journal	Number
Water Research	5/yr
Environmental Health Perspectives	1/yr
Environmental Science and Technology	3/yr
Journal of Environmental Engineering, ASCE	3/yr
Journal of American Water Works Association	2/yr
Water Environment Research	3/yr
(on Editorial Board of Review through 9/99, handling ~30 papers per year)	
other journals (e.g. *Biotech. Bioengr., Can. J. Microbiol., Biodegradation*)	~3/yr

Proposals:

Proposal Review Panels, Environmental Engineering, EPA, 1995, 1997, NSF 2001, 2002, 2005
others (NSF, Canadian NSERC, Hong Kong, Korea and Singapore research agencies,
regional agencies and foundations) ~4/yr

Awards and Honors

National Merit Scholar, 1959-1963
Tau Beta Pi, 1962
AEC Fellowship in Nuclear Science and Engineering, 1963-1964
EPA Predoctoral Fellowship, 1966-1969
EPA Postdoctoral Fellowship, 1969-1970
H.P. Eddy Award for Outstanding Research (Water Pollution Control Federation), 1974
H.P. Eddy Award for Outstanding Research (Water Pollution Control Federation), 1978
H.P. Eddy Award for Outstanding Research (Water Pollution Control Federation), 1984
Award for Best Research Paper, American Water Works Association, 1984
Academic Advisor to winner of 1984 AWWA Academic Achievement Award for best doctoral dissertation, 1984
Award for Outstanding Publication, American Water Works Association, 1988.
Award for Best Distribution System Paper, American Water Works, Association, 1990.
Berg Lecturer, Department of Civil Engineering, University of Washington, 1990.
Society of Scholars, Johns Hopkins University, 2002

Teaching, last 10 years

Course	Quarter	No. of Students	Course Title	Instructor's Avg of Items 1-4
CEWA 456	A1988		Aquatic Chemistry	3.70
CIVE 350	W1989		Envir. Engineering-Water & Air	
CEWA 556	Sp 1989		Industrial Waste Treatment	
CEWA 550	A1989		Biological Waste Treatment	
CIVE 350	W1990	80	Envir. Engineering-Water & Air	3.01
CEWA 470	W1990		Solid Waste Disposal	
CEWA 550	A1990	36	Microbiological Process Fund.	3.44
CEWA 456	A1990		Aquatic Chemistry	2.64
CEWA 470	W1991		Solid Waste Disposal	
CEWA 556	Sp1991	25	Industrial Waste Treatment	3.92
CIVE 350	A1991		Envir. Engin.-Water & Air	3.60
CIVE 485	A1992	29	Aquatic Chemistry	3.71
CIVE 350	W1993	82	Envir. Engineering-Water & Air	3.30
CEWA 550	A1993	26	Micro. Process Fundamentals	Form X
CEWA 551	W1994	18	Biological Treatment Systems	Form X
CEWA 550	A1994	27	Micro. Process Fundamentals	3.42

CIVE 350	W1995	86	Envir. Engineering-Water & Air	3.34
CEWA 550	A1995	25	Micro. Process Fundamentals	3.4
CIVE 350	W1996	63	Envir. Engineering-Water & Air	3.5
CEWA 550	A1996	13	Micro. Process Fundamentals	1.9
CIVE 350	W1997	62	Envir. Engineering-Water & Air	3.5
CIVE 350	A1997	40	Envir. Engineering-Water & Air	3.06
CEWA 550	A1997	10	Micro. Process Fundamentals	2.88
CIVE 485	W1998	14	Aquatic Chemistry	3.56
CEWA 558	S1998	9	Industrial Waste Treatment	
CEWA 550	A1999	18	Micro. Process Fundamentals	3.43
CEWA 551	W2000	11	Physical-Chemical Treatment Proc.	3.29
CIVE 350	S2000	58	Envir. Engineering-Water & Air	3.22
CEE 540	A2000	10	Micro. Process Fundamentals	
CEE 541	W2001	5	Biological Treatment Systems	
CEE 549	S2001	5	Advanced Environ. Engr. Topics	3.25
CEE 500 C/D	S2001	20	EES/HWR Seminar	
CEE 482	A 2001	14	Wastewater treatment	3.12
CEE 544	W 2002	7	Physical-Chemical treatment	4.32
CEE 350	S 2002	65	Intro Environmental Engr. Science	2.6

Short Courses, Workshops, and Other Educational Programs

Teaching workshop, March 30, 2001

Chaired Doctoral Degrees

G. Lee Christensen (JHU)	1972
Mark A. Anderson (JHU)	1974
John Eastman	1977
David N. Given	1978
Ronald D. Hilburn	1983
Sandra L. Woods	1985
Foroozan Labib	1989
Jao-Jia Horng	1993
Simeon J. Komisar	1993
Bhaskar Ballapragada	1996
Krista M. Anders	2000
Siwei Zou (continuing)	
Jaana Pietari	2002
Anne Conklin	2004
Hyun-shik Chang (co-advise with Korshin) (continuing)	

Chaired Master Degrees

David Refling (JHU)	1974
Elaine Friebele (JHU)	1975
David N. Given (JHU)	1975
Thomas A. King (JHU)	1975
George F.P. Keay	1975
Sylvia Burges	1976

Richard R. Spencer	1976
John P. Wilson-vanOsdel	1976
Cornelius J. Marx	1976
Karl B. Parrish, Jr.	1976
Steven M. Lellelid	1977
David W. Browne	1977
Ronald L. Horres	1977
Allan D.Kissam	1977
Ronald D.Hilburn	1977
Stephen M. Hart	1978
Mary S. Anderson	1978
Anne Crawford	1978
Kimberly A. Cox	1978
Sonthi Vannasaeng	1978
Wang-Cheng Tseng	1978
Mario Kato	1979
Paul Snyder	1979
Michael J. Brown	1980
Kurt H. Vause	1980
Sandra L. Woods	1980
Carlos Herrera	1980
Mark B. Buggins	1980
Paul S. Snyder	1980
Brian J. Eis	1982
David R. Nitchals	1983
Michael S. Kuenzi	1984
Karl R. Nordqvist	1985
James C. Ebbert	1986
Ronald S. Sletten	1987
Chung Feng Chung	1987
Byung K. Maeng	1987
Sheila J. Baran	1989
Gregory L. Pierson	1989
Christopher A. Arts	1989
Yun-Peng Shih	1989
John Galasso	1989
Mary I. Rumpf	1989
Eva Jonsson	1990
Dennis Ritter	1990
Laura Hodges	1991
Ronald A. LaFond	1991
Karl S. Bosworth	1992
William T. Leif	1992
Per H. Ollestad	1992
Patricia S. Perkins	1992
Ron L. Porter	1992
Grete Rasmussen	1992
John Ryding	1992
Sophia Gudmundsdottir	1993
Andy Haub	1993
Jean H. Lee	1993
Margareta Lundin	1993
Paivi Makinen	1993
Gro D. Ofjord	1993

Krista M. Anders	1994
Samuel A. L. Perry	1994
Stacy A. Koch	1995
Henning Mohn	1995
Matthew L. Hinck	1995
Kara Nelson	1996
Patricia A. Danowski	1997
Pamela A. Elardo	1997
Rebecca S. Maco	1997
Hao Wu	1997
Alice Lancaster	1997
Michael Boyle	1997
Siwei Zou	1997
Jaana M.H. Pietari	1999
Lisette L. Nenninger	1999
Cheryl Stadlman	1999
Janel Duffy	2001
Se-Yeun Lee	2002
Veronica Henzi (with J. Cooper)	2003
Pragya Singh (co-advise with G. Korshin)	2002
Jessica Satterberg	2004
Benni Jonsson (continuing)	
Tom Chapman (continuing)	
Dan Wang (continuing)	
Virpi Salo (continuing)	

Other Student Supervision (service on graduate degree committees):

not listed

Departmental Service, since 1988

1988	Civil Engineering Undergraduate Curriculum Review Committee
1988-1992	Chairman, Civil Engineering Undergraduate Education Committee
1988	Organizer, Evans Lectureship
1989-1991	Graduate Program Advisor, Environmental Engineering & Science
1997-1998	Chair, Centennial Reunion Planning Committee
1999-2000	Graduate Application Coordinator for Environmental Engineering & Science
2002-present	Undergraduate Admissions and Scholarship Committee
2002-2003	Coordinator for Environmental Engineering and Science Area
2004-2005	Coordinator graduate admissions for Environ. Engin. Science

College Service since 1988

1987-88	College Undergraduate Engineering Curriculum Review Committee
1991-present	Valle Scholarship and Exchange Program, Associate Director

University Service since 1988

1990	Graduate School Review Committee for Environmental Health Ph.D. Program
1997	Chair, Graduate School Review Committee for Department of Environmental Health
2003	Member, Graduate School Review Committee for School of Aquatic and Fishery Sciences

Community Service

Internal Corrosion Study Advisory Committee, Seattle Water Dept., 1975-76
Cedar-Tolt Watershed Management Advisory Committee, Seattle Water Dept., 1976-79
Toxicant Study, Scientific Advisory Panel, Municipality of Metropolitan Seattle, 1978-81

National Service, partial listing

Peer Review Panel for EPA Research Center at Illinois Institute of Technology, 1985
Western Regions Hazardous Substances Research Center, Scientific Advisory Board, 1985-92
EPA National Risk Management Laboratory Review Panel, 1997
American Water Works Association Research Foundation, member Materials Issues Group, 1998
NSF Review Panel, 2001, 2002, **2005**

Other Service, since 1996

Department of Civil Engineering Review, University of British Columbia, 1996
Department of Civil Engineering, University of Portland, Advisory Committee to Envir. Engr. Program, 1998

Consulting Experience, since 1990

Corrosion impacts for San Francisco, Santa Cruz, and Los Angeles water systems, Camp, Dresser, and McKee, Inc., 1990

Corrosion and blue water in East Bay MUD system; James M. Montgomery Engineers, 1990.

Corrosion evaluation for Santa Clara Valley Water District; Kennedy, Jenks, Chilton, 1991.

Corrosion evaluation for Portland Water Bureau; Economic and Environmental Services, Inc., 1992-94

Evaluate anaerobic bioremediation for Western Processing site, Landau Associates, 1993.

Consult on treatment of deicing wastewaters, Port Authority of Seattle, 1995.

Corrosion and red water evaluation for Tucson, AZ, CDM, 1996

Pollution of City Waterway, Tacoma, WA; Aitken, St. Louis, Siljeg, 1996-1997

Copper corrosion evaluation for Prescott, AZ, HDR Engineering, 1997

Evaluation of Anoxic Gas Flotation alternatives for King Co. DNR, Brown & Caldwell, 1999

Corrosion evaluation of treatment changes for Santa Clara Valley W.D., CDM, 1999

Corrosion study for corrosion inhibitors for City of Santa Cruz, CDM, 2000

Corrosion study for corrosion inhibitors and coagulant change for Santa Clara Valley Water District, 2001

Court-appointed expert on corrosion field testing, Judge Peter Lichtman, L.A. Co. Superior Court, February-July, 2001.

Evaluation of data from San Francisco PUC regarding turbidity in their transmission lines, CDM, 2002

Corrosion inhibition evaluation for CCWD/ City of Brentwood, CDM, 2004

Carol A. Rego, P.E.

Vice President

Education

B.S. – Civil Engineering, University of Massachusetts/ Dartmouth (1982)

Registration

Professional Engineer: Massachusetts (1988), Maine, Connecticut, Rhode Island, and New Hampshire

Ms. Rego has 25 years of experience in water and water supply. Her expertise includes treatability studies; process selection and drinking water research; Safe Drinking Water Act (SDWA) compliance; water supply planning; and water treatment plant evaluation, operations, and design.

Project Director/Technical Advisor. Ms. Rego serves as a senior project director and technical advisor for several drinking water projects in the New England Area including the Portland, Maine UV Disinfection Feasibility study; Reading, Massachusetts NDMA evaluation; Springfield Water and Sewer Commission optimization study; Lewiston and Auburn, Maine Safe Drinking Water Act compliance evaluation; water treatment plant upgrade for the City of Woonsocket, Rhode Island; and water quality consulting for the Providence (Rhode Island) Water Supply Board, including a 2-year lead and copper corrosion control optimization program.

Officer-in-Charge, City of Cambridge, MA Water Quality and Treatment Consulting. Ms. Rego is overseeing various projects for the City including optimization of mixing and water quality in the Payson Park finished water storage reservoir; disinfection tracer studies for enhanced treatment; and developing a long-term water supply strategy.

Officer-in-Charge, City of Newport, RI, Compliance Evaluation and Water Treatment Plant Improvements Projects. In response to new and upcoming drinking water regulations, the City of Newport undertook a comprehensive treatment evaluation, culminating in a plan of coordinated improvements to meet future regulations, as well as future water demands. The complexity of the Newport supply, treatment and distribution system further added to this challenge. This includes a complicated system of nine reservoirs having a wide range in quality that can change quickly. It also includes two treatment plants with different processes, one of which has equipment that is much beyond its useful life. Finally, the distribution system includes several pressure zones, several consecutive systems, and extended water age concerns. Ms. Rego is directing the city's systematic approach to achieving integrated treatment including:

- Detailed evaluation of distribution system water quality interrelationships between proposed disinfection modifications (chloramines) and corrosion control treatment. This includes a year-long pipe loop study evaluating the effects of various NOM-pH-Pb-ORP relationships.

- Audit inspection of treatment plants to identify physical and reliability deficiencies.

- Testing program including enhanced coagulation, organics removal optimization (MIEX), DBP formation kinetics, alternate coagulants, and alternate secondary disinfectant (chloramines).

- Short-term improvements including the addition of chloramines for secondary disinfection at both WTPs to reduce formation of disinfection byproducts, optimization of existing processes for TOC removal and CT compliance.

- Multi-pronged testing program including pipe scale analyses; bench-scale testing (chloramine decay, chlorine-to-ammonia ratio, DBP formation, coupon testing for metal (lead) release, corrosion rates, and scale formation); and limited pipe-loop testing.

Project Manager/Technical Manager, Lead and Copper Rule Corrosion Optimization/Control Studies. Ms. Rego has helped several New England utilities develop approaches for corrosion optimization under the Lead and Copper Rule. These communities include Salem/Beverly, Needham, New Bedford, Worcester, Wakefield, and Woburn, Massachusetts; Brewer, Lewiston and Auburn, Maine; and Newport, Providence, Westerly, Pawtucket and Woonsocket, Rhode Island. For the Rhode Island Department of Health (RIDOH), she conducted a corrosion control study for the state's 43 small surface and groundwater systems. She also assisted many of these communities with their public notification efforts.

Technical Manager, Lead and Copper Rule Corrosion Optimization/Control Studies. Ms. Rego assisted the Salem Beverly Water Supply Board (SBWSB) (Massachusetts) with optimization of their corrosion control treatment and development of a regulatory compliance strategy. After many years of being in compliance, the SBWSB exceeded the Action Level for lead. The program included review of historical data, establishing sampling plans for lead/copper (Pb/Cu) at the tap and water quality parameters (WQPs), bench-scale testing of alternative corrosion treatment strategies, implementation of the recommended treatment strategy, public notification/education program, and routine sampling for WQPs and Pb/Cu following changes in treatment.

Technical Specialist, Lead and Copper Rule Compliance, Various Industrial Clients. Ms. Rego conducted an engineering study to address lead and copper concerns in the IBM East Fishkill (NY) West Complex distribution system. This included development of a sampling and analysis plan to evaluate water quality parameters in the West Complex system followed by a detailed implementation plan for the recommended treatment modifications. Ms. Rego also provided lead and copper rule drinking water regulatory and technical expertise for a food processing facility located in Killingly, Connecticut and the Pratt & Whitney manufacturing facility in Middletown, Connecticut.

Honors/Awards

Massachusetts Society of Professional Engineers, Young Engineer of the Year (1992)

Dexter Brackett Award, Most Meritorious Paper: Journal of the New England Water Works Association (1997)

Project Manager, US Coast Guard Shipboard Technology Evaluation Program (STEP). The STEP is designed to encourage the voluntary installation and testing of onboard ballast water treatment systems on merchant vessels by offering "equivalency" to the new ballast water management regulation. The project includes: (1) A desktop assessment of currently available and advanced prototype ballast water treatment systems intended for use onboard vessels; (2) marine biology and civil engineering Review Panel; and (3) assistance in the review and upgrade of STEP standard documents.

Project Manager, Water Supply/Treatment Plan. For Manchester Water Works (MWW) in New Hampshire, Ms. Rego directed a yearlong study to develop a long-range view of MWW's water supply and treatment options along with a plan for how to implement this vision. Ms. Rego reviewed MWW's water supply situation from multiple perspectives ranging from supply source adequacy to the deterioration of aging facilities. Her work also included review of existing source and finished water quality data, the existing treatment process, current and proposed regulations, evaluation of the future Merrimack River supply quality, and establishment of treated water quality goals. She developed a series of supply and treatment alternatives that were evaluated on the basis of cost (capital, operational and life cycle), overall effectiveness in meeting the established water quality goals, and non-cost factors such as reliability, ease of operations, public acceptance, and environmental compatibility. Ms. Rego continued as the project manager for the design of the 50-mgd plant upgrade, which features ozone, new filters, additional clearwell capacity, provisions for UV disinfection, and improvements to the facility's electrical, structural and architectural systems.

Officer-in Charge, Water Distribution System and Water Treatment Upgrade Projects. Ms. Rego oversaw a chloramine conversion project for the City of New Bedford, Massachusetts, and the upgrade of a filtration plant for the Town of Wakefield, Massachusetts. She helped both communities secure State Revolving Loan Funding (SRF). Also for New Bedford, Ms. Rego is overseeing a water main rehabilitation project involving 29,000 feet of main replacement and relining. She is also responsible for completion of a transmission main reinforcement program for New Bedford involving line valve replacement on 42,380 feet of 48-inch cast iron and concrete main; 20,000 feet on twin 36-inch cast iron mains; and 22,750 feet of 42-inch concrete main.

Task Manager, Ultraviolet Disinfection Fouling Study. For New York City, Ms. Rego is the task manager for an ultraviolet disinfection fouling study for the unfiltered Catskill and Delaware surface water supply systems. The 12-month-long study will evaluate low pressure high output and medium pressure UV reactors in side-by-side testing. The study objectives are to investigate fouling potential on the exterior surfaces of lamp quartz sleeves (with and without chlorine addition upstream of the UV reactors); evaluate algae growth potential on surfaces distant from the UV lamps; independently evaluate the performance of each reactor's sleeve cleaning system (i.e., the cleaning systems for each reactor will not be compared to each other); and compile O&M information (e.g., cleaning regime, personnel requirements, etc.).

Task Manager, Water Quality and Treatability Studies. For New York City, Ms. Rego was the task manager for the water quality and treatability studies for the 1,900-mgd Catskill and Delaware surface water supply systems. She developed testing protocols and associated water quality sampling plans, and oversaw the direction and execution of a multi-year pilot study for the presently unfiltered New York City supply. Her work included accompanying source water quality studies to anticipate treatment challenges and future regulatory compliance issues.

Project Manager, Enhanced Disinfection Study. Ms. Rego's work for New York City also included a two-year disinfection study to investigate the use of alternative disinfectants (ozone, chlorine dioxide, chlorine, and UV) for primary disinfection under a continued filtration avoidance scenario. The study determined the appropriate disinfectant dose and system configuration to provide various levels of pathogen inactivation without subsequent filtration. Other objectives included evaluating multiple, sequential disinfectants for enhanced inactivation, determining the levels of biodegradable organic matter and disinfection byproducts produced, and assessing the impacts of an ozone disinfection alternative on the distribution system.

Officer-in-Charge and Technical Director, Flint's Pond Microfiltration Plant. Ms. Rego was the officer-in-charge for studies and design of a 1.6-mgd microfiltration plant for the Town of Lincoln, Massachusetts. As part of this work, she directed a 4-month pilot testing study for the town's presently unfiltered surface water supply—Flint's Pond. Her work also included source water quality and SDWA compliance assessments, and State Revolving Loan Funding (SRF). CDM provided construction management and inspection services for the project, which recently went into operation in the summer of 2003.

Task Manager, Pilot Testing. For the Philadelphia Water Department (PWD), Ms. Rego developed the protocols for a three-year pilot-testing program at its Baxter and Belmont plants. The focus of the first year was on short-term, low- or no-capital cost modifications to optimize the existing plants in light of regulatory compliance and cost issues. The second phase of the testing program evaluated alternative oxidant and advanced clarification methods. PWD will evaluate alternative disinfectants (focusing on ozone) in the third phase.

Project Manager, Information Collection Rule Program. Ms. Rego was the project manager for Information Collection Rule (ICR) sampling programs for the City of Brockton, Massachusetts, and for the Massachusetts Water Resources Authority (MWRA), Boston. She also directed ICR pilot studies for the City of New Bedford, Massachusetts, and rapid small-scale column testing

(RSSCT) studies for Brockton, Massachusetts, both evaluating granular activated carbon (GAC) for precursor removal.

Technical Advisor, Water Quality Assessment. Ms. Rego was a technical advisor for the Drinking Water Quality Assessment and Improvement Program for the District of Columbia Water and Sewer Authority (WASA). Her work included reviewing and evaluating water treatment and distribution system water quality and operating practices to develop recommendations and an implementation plan to improve the District's compliance with the Total Coliform Rule (TCR).

Task Manager, Distribution System Water Quality Improvement Program. Also for MWRA, Ms. Rego was the special task manager for the distribution system water quality improvement program. She developed a program to revise the primary and secondary disinfection practice to improve distribution system residuals and improve compliance with the Total Coliform Rule. System features included open reservoirs, rechlorination following initial chloramination, and simultaneous implementation of new corrosion control treatment. She participated in a water quality workshop for MWRA staff and community representatives on integrating corrosion control and disinfection improvements.

Project Manager, Water System Improvements. For water system improvements conducted for the City of Worcester, Massachusetts, Ms. Rego's duties included project coordination and preparation of plans and specifications for a $65 million capital improvement project being constructed under eight construction contracts. These contracts include a 50-mgd water filtration plant, pump station modifications, water storage tanks, raw and finished water transmission mains, and distribution system improvements. Also included are design, construction, and operation of the pilot testing facility; preliminary design; detailed site selection studies; plant design criteria; plant layout; analysis of distribution systems; storage and pumping facilities; and cost-effective analyses. Ms. Rego was responsible for all permitting and public education requirements associated with the project.

Project Manager, Operator Training and Startup. Ms. Rego developed and conducted operator training and oversaw the start-up of the Worcester water filtration plant, featuring on-line particle counters for each of the eight filters, and the source and finished water. The plant achieves greater than 3-log particle removal in the *Giardia* and *Cryptosporidium* size range and exceeds all production and water quality goals.

Technical Director, Water Treatment Plant Studies. Ms. Rego was also the technical director for the Pilot Plant Studies, Quittacas WTP (45 mgd) in New Bedford, Massachusetts. The project evaluated the technical, water quality, and cost issues to convert from full conventional treatment to direct filtration and to convert from free chlorine to chloramine residual disinfection.

Project Engineer, Water System Improvement Project. Ms. Rego was project engineer for the final design of Worcester's major water system improvements project. This project received an ACEC award for engineering excellence. She prepared plans and specifications and provided multidisciplinary coordination for eight construction contracts that included a 50-mgd water filtration plant, five water storage tanks, pump station modifications, raw and finished water transmission mains, and distribution system improvements.

Project Engineer, Facilities Plan. Ms. Rego also served as project engineer for a facilities plan and preliminary design for ozone primary disinfection facilities for the Portland Water District in Maine. In this role, she was responsible for the technical completion of the project, including site selection studies and facilities layout. She was also project engineer for an SDWA Impact Study for the Bridgeport Hydraulic Company in Connecticut.

Process Consultant, Water Treatment Plant. Ms. Rego conducted a water treatment plant process study for the Town of Weymouth, Massachusetts. She was also a project engineer for a 10-mgd water treatment facility at Ludlow Reservoir in Springfield and for water treatment studies for the Champlain Water District in South Burlington, Vermont.

Process Consultant, International Water Treatment Plant Projects. Her international work includes serving as process consultant for the Treatment Process Upgrade Program, Public Utilities Board, Republic of Singapore. Other international work includes serving as a Process Consultant for Siu Ho Wan (40 mgd), Ma On Shan (60 mgd), and Ngau Tam Mei (120 mgd) Treatment Works, Hong Kong Water Supplies Department.

Professional Activities

Organizing Committee, National Academy of Engineering, 2007 US Frontiers of Engineering Symposium, Redmond, WA.

AWWA Research Foundation, Research Advisory Council, 1998-2004

AWWA Research Foundation, Research Chair, Customer Workgroup of the Research Advisory Council, 1999 and 2000

AWWA Research Foundation, Research Chair, Environmental Leadership Workgroup of the Research Advisory Council, 2001–2003

U.S. Environmental Protection Agency (USEPA) National Drinking Water Advisory Council (NDWAC) Working Group on Research, 2000-2002

AWWA Research Foundation, Project Advisory Committee for Improvement of the Ozonation Process Through the Use of Static Mixers, 1998-2000

Invited Participant – Drinking Water Research Needs Expert Workshop, sponsored by USEPA and AWWA Research Foundation, Leesburg, Virginia, September 1999

AWWA Research Foundation, Project Advisory Committee for Optimizing Filtration in Biological Filters, 1995-1999

Publications/Presentations

Case Studies in the Integrated Use of Scale Analyses to Solve Lead Problems, with M.R. Schock, National Risk Management Research Laboratory, USEPA, Cincinnati, Ohio, 2007 AWWA Distribution Research Symposium, Reno, NV, March 3, 2007.

Understanding the Relationship Between Organic Precursor Fractions and Formation of NDMA and CNX in a Groundwater Supply, with D.A. Reckhow, University of Massachusetts, proceedings of the AWWA Water Quality Technology Conference, Denver, Colorado, November 6, 2006.

Two Approaches to Address Calcium Carbonate Scaling Resulting from Optimal Corrosion Control Treatment, AWWA Inorganic Contaminants Workshop, Austin, Texas, January 31, 2006.

Simultaneous Compliance Issues with Corrosion Control BAT: More than Just Primary Standards, with W.T. Wanberg, Town of Needham and M.R. Schock, U.S. EPA, AWWA Water Quality Technology Conference, Quebec City, Quebec, November 2005.

Case Studies – LCR and DBPR Simultaneous Compliance, Virginia AWWA Section Drinking Water Quality Committee Seminar, Richmond, VA, April 13, 2005.

Case Study: One City's Long-Term Strategy to Balance Multiple Water Quality Objectives, with James Ricci, Water Superintendent and Charles Kennedy, Assistant Superintendent, City of New Bedford, presented at the New England Water Works Association Water Quality Symposium, Boxborough, MA, May 19, 2005.

Lead and Copper Corrosion Control Theory Update, with M.R. Schock, U.S. EPA, Cincinnati, OH, NEWWA Spring Joint Regional Conference and Exhibition, Worcester, Massachusetts, April 6, 2005.

Evaluating and Improving Water Quality in Distribution Storage Reservoirs, with T.W. D. MacDonald, Manager of Water Operations, Cambridge Water Department, presented at the NEWWA Spring Joint Regional Conference and Exhibition, Worcester, Massachusetts, April 6, 2005.

Controlling Both Calcium and Lead: A Unique Situation in New England, with William T. Wanberg, New England Water Works Association Annual Conference, Newport, Rhode Island, September 21, 2004.

Selection, Construction and Operation of Membranes for a Small System, New York Section of the American Water Works Association Spring Meeting, Saratoga Springs, New York, April 29, 2004.

Chloramine Conversion: What Distribution System Changes Should You Expect? with James Ricci and Charles Kennedy, NEWWA Spring Joint Regional Conference and Exhibition, Worcester, Massachusetts, March 31, 2004.

Prepare Now for Public Notification, NEWWA Spring Joint Regional Conference and Exhibition, Worcester, Massachusetts, April 2002.

Implementing the First Surface Water Microfiltration System in Massachusetts, with L. Sorgini, proceedings of the American Water Works Association Membrane Technology Conference, San Antonio, Texas, March 2001.

Manchester's Water Supply and Treatment Plan, with David B. Paris, NEWWA ~ NHWWA ~ GMWEA Meeting, West Lebanon, New Hampshire, January 2001.

The Feasibility of Constructing a Medium-Pressure UV Facility for New York City's Catskill and Delaware Supplies, with O. Schneider, J. Herzner, D. Nickols, and D. Malanchuk, proceedings of the American Water Works Association Water Quality Technology Conference, Salt Lake City, Utah, November 2000.

Microfiltration: Meeting Water Quality Challenges for Small Systems, with L. Sorgini, proceedings of the American Water Works Association Annual Conference, Denver, Colorado, June 2000.

Impacts of Corrosion Control on Heavy Metals Concentrations: Three Years of Operating Experience, New England Water Environment Association Spring Conference, Bretton Woods, New Hampshire, June 5, 2000.

Treating Waste Filter Backwash with Low Pressure Membranes, New England Water Works Association Water Quality Symposium, Boxborough, Massachusetts, May 2, 2000.

Ultraviolet Light (UV) Disinfection for Drinking Water, with D. Nickols, Edwin C. Tifft Jr. Water Supply Symposium, New York Section of the American Water Works Association, Liverpool, New York, October 20, 1999.

Microfiltration: Meeting Water Quality Challenges for Small Systems, with L. Sorgini, New England Water Works Association Annual Conference, Burlington, Vermont, September 22, 1999.

A New Look at an Old Technology: Slow Sand Filtration, with S. Tarallo, proceedings of the American Water Works Association Annual Conference, Chicago, Illinois, June 1999.

Worcester Corrosion Control Retrofit – An Example of a Project Partnership Approach, with R. Hoyt and P. Guerin, Joint Regional Operations Conference, New England Water Works Association, Worcester, Massachusetts, April 7, 1999.

Alternatives to Achieve Enhanced Disinfection for New York City, with J. Herzner et al., Proceedings, International Ozone Association, Pan American Group Annual Conference, Vancouver, British Columbia, October 1998.

Newsletters Are Consumer Friendly, Joint Regional Operations Conference, New England Water Works Association, Marlborough, Massachusetts, April 1, 1998.

Implementing Corrosion Control Treatment: Balancing Water Supply and Wastewater Needs Through a Partnership Approach with R. Moylan and T. Walsh, Proceedings, WEFTEC '97, Chicago, Illinois, October 1997.

Do Interim Improvements Prior to Permanent Facility Construction for SWTR Compliance Provide Worthwhile Public Benefit? with S. Seckinger et al., proceedings of the American Water Works Association Annual Conference, Atlanta, Georgia, June 1997.

Round Robin HAA Testing Prompts Uncertainty in USEPA Method 552.1, with S. Seckinger and J. Occhialini, proceedings of the American Water Works Association Water Quality Technology Conference, Boston, Massachusetts, November 1996.

Balancing Corrosion Control, Disinfection and Distribution System Water Quality for Boston, with B. Johnson, et al., proceedings of the American Water Works Association Water Quality Technology Conference, Boston, Massachusetts, November 1996.

Pushing the Envelope: Integrating Ultra-High Clarification and Filtration Loading Rates, American Water Works Association, Engineering and Construction Conference, Denver, Colorado, March 1996.

Ozone Applications for Filtration and Non-Filtration Alternatives, International Ozone Association Pan American Group Conference on Ozone for Drinking Water Treatment, Cambridge, Massachusetts, November 1995.

Evaluating Contract Operations for a New Water Filtration Plant, with R. Moylan and J. Ridge, presented at the American Water Works Association Annual Conference, Toronto, Canada, June 1996.

Washwater Recycle Optimization, presented at the American Water Works Association Annual Conference, Anaheim, California, June 1995.

Dissolved Air Flotation Optimization: A Case Study, with D. Nickols, et al., poster presentation at the American Water Works Association Annual Conference, Anaheim, California, June 1995.

Pilot Scale Evaluation of Residuals Management Options, with S. Seckinger, et al., poster presentation at the American Water Works Association Annual Conference, Anaheim, California, June 1995.

Treatment Process Strategies to Meet Varying Water Quality Goals: Evaluating the Costs and Benefits, poster presentation at the American Water Works Association Water Quality Technology Conference, San Francisco, California, November 1994.

The Crypto Challenge: Optimizing Treatment For Cryptosporidium Control, New England Water Works Association Annual Conference, Montreal, Quebec, September 1994.

Small System Compliance: CT Versus DBPs, Proceedings of the American Water Works Association Annual Conference, New York City, June 1994.

Small System Compliance: CT Versus DBPs, Proceedings of the American Water Works Association Engineering Design Conference, Cincinnati, Ohio, March 1994.

Water Treatment Plant Siting: Balancing Public, Environmental and Engineering Needs, with R. Moylan et al., Proceedings of the American Water Works Association Annual Conference, San Antonio, Texas, June 1993.

Optimization and SDWA Compliance at a New England Water Treatment Plant, with J. Buckley et al., New England Water Works Association, Randolph, Massachusetts, December 1992.

Review of the New Lead and Copper Regulations, Maine Water Utilities Association, Old Town, Maine, October 1991.

Removal of Total Oxidant Species of Chlorine Dioxide Disinfection by Granular Activated Carbon, with J. Thompson, Proceedings of the American Water Works Association Annual Conference, Cincinnati, Ohio, June 1990.

Evaluation of Alternative Water Supplies for Worcester, Massachusetts, New England Water Works Association, Milford, Massachusetts, May 1988.

Ozone-Direct Filtration for the Worcester Water Supply, with P. Prendiville et al., Proceedings of the American Water Works Association Annual Conference, Kansas City, Missouri, June 1987.

JOHN S. YOUNG, JR.

Home:
109 Kingsdale Avenue
Cherry Hill, New Jersey 08003
856-424-0718

Business:
American Water
1025 Laurel Oak Road
Voorhees, New Jersey 08043
856-346-8250

Education:
B. S. Civil Engineering, Duke University, 1975;
M.S. Environmental Engineering, University of North Carolina at Chapel Hill, August 1977 (two year program)

Professional Summary

John Young joined the American Water System in 1977 as the Director of Water Quality for the Eastern Division. He held increasingly responsible positions in engineering and water quality and in 1991 was named Vice President – Engineering. In this position, he was responsible for planning, capital program delivery, operational enhancements and employee development. Mr. Young has been active in and held leadership positions in a number of professional and civic organizations. Mr. Young has more than 25 years of experience in the planning, design, construction management and operation of water and wastewater systems. He has also provided expert testimony and lectures in those areas. During 2000 and 2001, Mr. Young was the integration lead for the major acquisition of Citizens Water Resources.

John Young is Chief Operating Officer (COO) of American Water and holds a seat on the company's Board of Directors. He was responsible for a wide range of corporate functions, including identifying and implementing operational improvements; managing the Americas Region capital program; and directing risk management in the areas of health and safety, security and event management. He was also responsible for environmental compliance, management, and stewardship; engineering; research and technology; and assessment of commercial and growth initiatives.

Young is an active member of several professional organizations, including a Board Member of the Design/Build Institute of America and past New Jersey AWWA Section Chair and Fuller Awardee. He also serves on the USEPA National Drinking Water Advisory Council (NDWAC).

Employment Record:

Chief Operating Officer
10/05 – Present

American Water
Responsible for developing and integrating the Company's strategic plan including establishing balance between the company's immediate business goals and long-term vision, developing and implementing policies, procedures and standards, as well as maintaining and enhancing the

company's image and quality service.

Vice President – Operations and Investment Performance
11/03 – 10/05

American Water
Responsible for the following functions/activities:

1) Identifying and implementing operational improvements, and efficiencies and best practices across the business;
2) Managing the Americas Region $600M capital program;
3) Risk Management – Health & Safety, Security and Event Management;
4) Environmental compliance, management and stewardship;
5) Engineering;
6) Research & Technology.
7) Assessment of commercial and growth initiatives.

Vice President – Technical Services
1/03 – 11/03

American Water
Responsible for managing the American Water technical services including the engineering, environmental management and research functions. Additionally, responsible for improving business performance through identifying and implementing operational efficiencies, material procurement and energy management initiatives. Provide technical leadership for commercial opportunities to maximize value and performance.

Vice President – Engineering
4/91 – 1/03

American Water Works Service Co., Inc.
Responsible for managing the engineering function of the American Water System. This includes the preparation of comprehensive planning studies for system operations in twenty-two (22) states and the design, design overview and construction management or projects involving water supply, treatment, pumping, distribution and transmission facilities. Responsibilities also include development of engineering standards, project management procedures, employee development and business development.

Director – Engineering Design
1/86 – 4/91

American Water Works Service Co., Inc.
Responsible for managing engineering design for American System Engineering Office. Responsibilities include:

1) Review and approval of in-house design of water treatment, pumping and storage facilities.
2) Development of detailed design concepts and coordination of water works design and construction.
3) Pilot plant testing and start-up of new or expanded facilities.
4) Instruction at training seminars.
5) Technical presentations.
6) Expert testimony.

Director – Engineering Planning **9/84 – 12/85**	**American Water Works Service Co., Inc**. Responsible for managing engineering planning for American System Engineering Office. This group developed Comprehensive Planning Studies for water systems which included water demand projections and regional water supply plans, analysis of sources of supply and production facilities and modeling of distribution systems.
Supervising Engineer **10/82 – 9/84**	**American Water Works Service Co., Inc.** Served as project engineer for the major design projects within System Engineering Office and supervised personnel on other design and planning projects.
System Environmental Engineer **12/79 – 10/82**	**American Water Works Service Co., Inc**. Project engineer with primary responsibility for process, hydraulic, chemical feed and instrumentation and control design and coordination of structural, electrical and HVAC for new and renovated water works facilities. These facilities included turbidity removal, greensand filtration, lime softening, GAC adsorption, air stripping and residual solids processing.
System Water Quality Engineer **10/78 – 12/79**	**American Water Works Service Co., Inc**. Evaluated the performance and efficiency of treatment facilities for American System Water Quality Office.
Director of Water Quality – Eastern Division **9/77 – 10/78**	**American Water Works Service Co., Inc.** Responsible for the review and implementation of recommendations to improve finished and raw water quality, treatment efficiency and laboratory.
Teaching Assistant **9/76 – 6/77**	**University of North Carolina** Involved the preparation and instruction of laboratory exercises for three graduate level courses in water and wastewater unit processes.
Student Research Assistant **9/75 – 9/76**	**Bogue Sound Water Quality Study** **University of North Carolina** Duties included field sampling and collection of background data to develop recommendations for pollution abatement.
Assistant Engineer **1975, 1976 (part-time)**	**Wiggins-Rimer & Associates** Collection and analysis of watershed and stream flow data for 208 regional water quality/quantity planning studies.
Professional Certifications	Registered Professional Engineer in multiple states.
Professional Organizations:	**National Drinking Water Advisory Council (2001-___)** NDWAC Affordability Workgroup NDWAC Water Security Workgroup

American Water Works Association
Standards Council Member
Chair – AWWA/ASDWA Additives
1992-1994 New Jersey Section Program
1994-1999 New Jersey Section Board of Trustees
1997 New Jersey Section Chair
1994 Fuller Award Recipient

American Society of Civil Engineers
Design/Build Institute of America – Board Member

Civic:

Trinity Presbyterian Church
1989 – 1992 Board of Deacons
1992 Moderator – Board of Deacons
1994 – 1996 Elder – Session
1996 President – Board of Trustees
1998 Chair - $1.5 Million Capital Campaign

Presentations and Publications:

- "Emerging Water Utility Trends" presented at the New Jersey Section – American Water Works Association, March 2007.

- "Effective Water Utility Management – Goals, Performance, Planning & Leadership" presented at the New Jersey American Water Works Association Seminar, February 2007.

- "Challenges and Benefits of Total Water Management" Published in *Underground Infrastructure Management*; November/December 2006.

- "Challenges and Benefits of Total Water Management", Published in *Journal* of the American Water Works Association; June 2006.

- "A Paradigm Shift for Owners", Design-Build and the Water/Wastewater Sector: Risks and Opportunities, Published in *Design-Build DATELINE*; January 2006.

- "Emerging Water Utility Trends" presented at the Association of Metropolitan Water Agencies, 2005 Annual Meeting; October 2005.

- "American Waters Business Process Transformation: Enhancing Asset Management" presented at the American Water Works Association, National Convention; June 2005.

- "High Performance Supply Chain" presented at the International Utilities and Energy Conference – Barcelona, Spain; April 2005.

- "Affordability: An Industry Perspective" presented at the National Association of Water Company Conference; October 2004.

- “Small Systems Affordability” presented at the National Association of Regulatory Utility Commissioners (NARUC) Conference; February 2003.

- “Automation and Instrumentation, Making the Most of Technology in Our Operations” presented for American Water Works Association teleconference; November 2000.

- “The Future of Drinking Water Treatment” presented to the American Water Works Association – Water Quality Technology Conference; November 1999.

- “Waste Stream Recycle” presented to U.S. EPA Stakeholders Meeting for Filter Backwash Recycle Rule; July 1998.
- “Innovative Project Delivery Techniques” presented to the American Water System – Annual Business Forum; April 1997.

- “Facility Reliability and Reserve Capacity” presented to the American Water System – Annual Business Forum; May 1996.

- “Facility Automation” presented to the American Water System – Annual Business Forum”; May 1995.

- “Source Remediation” presented to the American Water System – Annual Business Forum”; May 1995.

- “Industry Leadership through Participation in Water Industry Activities” presented to the American Water System – Annual Business Forum; May 1994.

- “Preparing a Request for Proposal” presented to the American Commonwealth Management Service meeting; March 1990.

- “Using Technology as a Management Tool – Management through Facility Design” presented at American Water System Management Seminar; May 1988.

- “Process Selection for Arsenic Removal” presented to the Indiana Section – American Water Works Association; November 1987.

- “Pilot Treatment Studies for the Kentucky River” presented to the Kentucky-Tennessee Section – American Water Works Association; September 1987.

- “On-Line Instrumentation – Practical Consideration” presented to the New Jersey Section – American Water Works Association; March 1986.

- “Pilot-Scale Investigation of Air Stripping for Removal of Volatile Organics” presented to New Jersey Section – American Water Works Association; September 1981.

- “Utilization of Belt Filter Press for Dewatering Water Treatment Plant Sludge” presented to the New Jersey Section – American Water Works Association; September 1981.

- “Operating Experience with Granular Activated Carbon” presented to the New Jersey Section – American Water Works Association; September 1979.

- “Chloroform Formation in Public Water Supplies: A Case Study” presented to the 97th Annual Convention of the American Water Works Association; May 1977. Published in *Journal* of the American Water Works Association; February 1979.

- “Adsorption of Alkyl Phenols by Activated Carbon”; Singer, Yen, Young; presented at American Chemical Society – Division of Environmental Chemistry; September 1978.

- “Adsorption of Phenolic Constituents of Coal Conversion Wastewaters”; Singer, Yen, Young; presented at the Purdue Industrial Waste Conference; 1977.

Guest Lecturer: Johns Hopkins University: “Pilot Studies for Process Selection”.
Rowan University: “Challenges in the Water Industry”.
Lehigh University: “Water Treatment Process Selection Criteria”

Instructor: American Water System – Water Treatment Plant Design Course.

Appendix II: Peer Reviewer Comments

Peer Review of “Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events”

REVIEWER COMMENTS

Reviewer #1

EPA Question	Reviewer Comments	Reference (Page in Document)
General Comments		
The organization of the chapters isn’t clear to a reader. The report needs a roadmap, just a paragraph at the end of chapter 1 that says LMP data will be presented and analyzed in Chapter 2, …. And the evidence about all the causative factors will be evaluated and presented in Chapter 5…etc.		Chapter 1
The readability of the figures, when printed in black and white, is problematic in several cases, which I will note below. The text should certainly omit references to the color of data symbols and lines. Even in this era, it is too much to assume that all readers will view the report on their computers or have a color copy available. Please review the figures in black and white and make the necessary adjustments. Some are just fine, but others could be improved.		
Much of the literature on the D.C. lead issue is in the gray literature and may not be available to many readers. I include WQTC Proceedings, AwwaRF reports, reports to DCWASA and EPA and all the internal DCWASA information. When these sources are used, it is important to include more information about what the study entailed and what the results are. I will note instances where I think more explanation is needed.		
At several fairly key points in the presentation extensive lists of citations are given. In one case (p.48), when I went to the papers that I could access (3 in journals. The other 7 in are in gray literature.) I found that two of them had no data that supported the statement in the text. Please be sure that a citation has specific information that supports a specific statement in the report.		
Paragraph 2, line 2. The term “consecutive” system (also used in the Executive Summary) doesn’t have a common meaning to many readers. Either explain or just omit the word.		Page 1
1st Paragraph 3 line 6 should change as to because		Page 1
Last Paragraph line 2 add lead-tin before solder		Page 1
Paragraph 2, Two issues with the causative mechanism		Page 4
Paragraph 2, line 6 delete “major” before Pb (IV) solids. There weren’t any others identified, or even considered.		Page 4
Last Paragraph, line 1 change became to were		Page 4
Paragraph 1 The presence of brass and bronze fittings in the service connection and consumer plumbing should be acknowledged.		Page 5
Need to provide an overview of what is to come in the report.		Page 6
Paragraph 2, line 1 should read “lead, copper and iron, using EPA		Page 7
The reanalysis of the LCR reports is somewhat interesting, but not very important, since only the Jul-Dec 1992 values change significantly. I would like to know if all sites were selected with lead service lines, or if some had copper with lead-tin solder plumbing. A little more information about the sampling protocol would be appreciated.		Page 8 & 9
Same point as above. The detailed explanation of the small differences between the reported and the reanalyzed results doesn’t add much to the reader’s understanding of the problem. Given the lack of information about how DCWASA did their analysis, we can’t even get insight into why the differences occurred.		Page 12
The pH story for the plants and the distribution system is complicated and important, regarding Pb (II) solubilities. At this point, we can see that the pH at the entry points seems basically ok, considerably above the allowable minimums in warm weather. The distribution system picture is less clear. It looks like there are a few values below about 7.3, which really doesn’t tell us much. However, when a much larger data base is presented in Figure 28, it is clear that there was a much more prominent period of low pH values that may have had a lot to do with Pb (II) solubility and high lead levels. It is too bad that the initial data set misleads the reader. Perhaps words could be added that would make the reader aware that the story is going to be more complicated and clearer about low pH values in the distribution system.		Page 13

Peer Review of "Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events"

REVIEWER COMMENTS

Reviewer #1

EPA Question	Reviewer Comments	Reference (Page in Document)
General Comments (continued)		
Figure 1. I suggest that the authors try using small symbols (x) with different shapes. The gray squares form a band with little information discernable about the black diamonds (Dalecarlia plant) data.		Page 14
Paragraph 1 last line. Please don't refer to the red line.		Page 15
Figure 2. The figure seems to have several different data symbols, but there is no explanation about what distinguishes them.		Page 15
I know that the purpose of the report isn't to place blame for the crisis that the high lead levels created. But the partial LSL replacement activities by DCWASA certainly has to rank high on a list of ineffectual actions. I think the details on the number of partial and the number of complete replacements should be incorporated into the report. Were lead profiles done at any houses where a complete replacement was done?		Page 16
Figure 7 solid line segments would be easier to see. (as used in Figure 9)		Page 20
Figure 11 The chlorine burn data are almost impossible to distinguish from the chloramine data.		Page 25
It isn't clear to me why some of the profile results are discussed here and others in Chapter 5. In that connection I don't see the relevance of the sentence about one home being sampled before and after partial LSL replacement.		Page 29
The point that LSLs are a primary source of lead is clear. However, I don't think the method of subtracting the "background" sample values is justifiable. The lead in those samples surely comes from the LSLs, too. If there are actual measures of lead in distribution main pipes (Keefer and Giani, 2005), then those values could be used to indicate the contribution due to the mains. Please tell us what Keefer and Giani measured.		
The calculation of a percentage contribution to the lead concentration is hard to interpret, especially since the overall average concentration isn't defined or presented. Figure 14 could be replaced by a table with average concentrations for the 1st liter, for the rest of the premise plumbing, for the LSL and for the main (based on samples from the mains). These values should be presented along with the average volume of water in the first three categories, and the concentration and volume should be multiplied to give the average contribution of lead from the three source areas for the lead profiles. Standard deviations for concentrations, volumes and mass loadings should also be presented.		
In calculating these concentrations and mass contributions, I think it would be justified to separate samples collected during chloramination, from those affected by the chlorine burns and the orthophosphate addition. It might be informative to present the average results for each of these periods.		
It should be pointed out that lead levels in quite a few samples of flowing water, originating upstream of the LSLs, had lead concentrations consistently exceeding the action level. This indicates that for these homes nearly all the water likely had high lead concentrations.		
Section 4.2.3. It would be better just to present the concentrations in the source water and from distribution main samples. The argument about diffusion and dissolution from LSLs should be in the previous section, as an explanation for the anomalous values seen in the lead profiles and as a justification for ***not*** subtracting the 0 or 00 lead levels.		Page 30
Table 7. The statement about Giani, et al should be modified. "Large fractions of" particulate lead occur in…		Page 36
Figure 17. Several minor points. Could add dates of chlorine burn periods. If it is possible, it certainly would be easier to read these figures with the x-axis labeled with simple dates, like 1/97, 7/97, 1/98, 7/98 etc. Trying to read the exact dates, see the very small (sometimes obscured) mark on the axis, and figure out when something happened, is pretty difficult. The orthophosphate addition should be marked with a horizontal arrow, like the other treatment changes.		Page 37
Figure 21. It is stated that this house had a partial LSL replacement, but the volumes associated with the LSL seem to change in the two profiles. What was going on?		Page 43

Peer Review of "Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events"

REVIEWER COMMENTS

Reviewer #1

EPA Question	Reviewer Comments	Reference (Page in Document)
General Comments (continued)		
First paragraph. This discussion of ORP has the same problems that I discussed above. The measured ORP is not a thermodynamic oxidation reduction potential in nearly every case because it responds to all oxidation/reduction couples in a highly non-linear fashion, depending on how active each couple is on the electrode surface.		Page 47
Measured ORP levels need to be described more. Are these simply the recorded values? If so, tell us what the reference electrode was. If they are corrected to the standard hydrogen electrode scale (E_H), then this needs to be stated.		
Oxygen should be added to the list of water quality variables that affect measured ORP values.		
Last paragraph. Schock, 2001 isn't in references. Do you mean Schock, et al. 2001? I read the three papers that are in journals in this series of ten citations. Two of the three do not present evidence in support of the statement that Pb (IV) is in scale on LSLs. Please review use of citations, so that cited work has specific information that supports the specific statement in the text.		Page 48
1st Paragraph, line 5. The statement that "Pb (IV) solids convert" is not clear. They must be reduced to Pb (II) to become more soluble, and if they are reduced, then some other substance must be oxidized. They hypothesis about causation has a significant gap.		Page 49
2nd Paragraph. Line 6. Very little has been said previously about the role of high free chlorine residuals. This probably is a good point, at least in that the higher chlorine dosages probably maintained chlorine residuals into the service lines and consumer plumbing and provided enough oxidizing capacity to form significant amounts of PbO_2		Page 49
Last Paragraph. Line 1. The relation between free chlorine and measured ORP should be shown, perhaps as a plot of free chlorine concentration vs. ORP. The logarithmic relation that is alluded to actually would predict a very weak dependence of ORP on chlorine concentration over the range used in D.C.		Page 49
2nd Paragraph. 1st sentence. The sentence isn't clear. It can be improved some by saying "If an orthophosphate inhibitor had been added", but the point about Pb (II) phosphate scales being protective is a) either very obvious based on experience of many utilities or b) completely unknown if the authors are thinking that free chlorine would still have oxidized Pb to form Pb (IV).		Page 50
This paragraph is a very important summary of the hypothesized causation of high Pb levels. The roles of free chlorine and low pH are very reasonable. There is a need for a mechanism of Pb (IV) reduction and a statement that the lead levels found in the lead profiles are reasonably consistent with Pb (II) solubility at pH between 7 and 7.5. The effort to make comparative statements about other systems are less convincing. There is no data presented that relates to other systems' free chlorine or measured ORP levels and the occurrence of Pb (IV). The purpose of the last two sentences isn't clear to me. The last sentence makes it clear that DCWASA has a fairly low alkalinity, which has been stated before. The preceding sentence may be intended to imply that maybe Pb (IV) is present in these field studies. However, if it just a statement that many high alkalinity systems have lower lead levels that Pb (II) solubility would indicate, that point probably isn't necessary.		Page 51
2nd paragraph, line 6. The sentence seems to be an overstatement of what ORP measurements indicate. I'd suggest saying. The transformation of existing Pb (II) to Pb (IV) is not well understood beyond the presence and absence of free chlorine and the corresponding measured ORP values.		Page 52
3rd paragraph. The second sentence could be restated: The solubility constants of PbO_2, $Pb_3(OH)_2(CO_3)_2$ (hydrocerussite) and $PbCO_3$ (10^{-66}, $10^{-18.8}$ and 10^{-13}, respectively) allow calculations that show PbO_2 is much less soluble than the Pb (II) solids.		Page 52
4th paragraph. The observation by Schock and Giani that Pb (IV) solubility tends to decrease with decreasing pH needs to be explained, since it certainly isn't the usual pattern for metal oxides. This is a case of a significant observation from a non-accessible source needs some explanation so the reader can understand why the authors are drawing their conclusion.		Page 52

REVIEWER COMMENTS

Reviewer #1

EPA Question	Reviewer Comments	Reference (Page in Document)
General Comments (continued)		
Last line. An explanation of what Schock and Giani did is needed, e.g. what minerals in the films, how much of a pH change, etc.		Page 53
3rd paragraph. The point about travel times in the distribution system hardly needs to be noted given the scale of the Figure. You really couldn't see a delay of 2 or 3 days in the data in even if it were uniformly present.		Page 54
Regarding pH in distribution system. It appears that the much larger pH decreases in 2001 and 2002 correlate with lower alkalinities (I'm not real clear whether this is source water or finished water alkalinity), but some discussion is needed of why the many low pH values were found.		Page 55
2nd para. 3rd sentence. The sentence isn't clear. Does the last phrase mean that the solubility minimum may be a pH values that are slightly acidic? If the details of the predicted solubility of Pb (IV) are given, it may be very clear.		Page 56
4th sentence. Schock 2004 isn't in references.		Page 56
Line 6 change "appeared to be" to "was".		Page 56
Omit references to blue and yellow lies in Figure 30.		Page 56
Figure 30. I suggest including pH data even for the non-LCR monitoring periods, especially for July-Dec. 2002. The correlation of pH and alkalinity (Figure 32) is important to see. Also, I think it would be better it the lead values weren't connected with a line—just use a nice, big symbol on the data point.		Page 57
Figure 31 and Figure 33. These figures show almost nothing. We know that lead was higher post-OCCT, but probably because chloramines were used and the pH was too low. We also know that lead was lower pre-OCCT, but this is because the change to chloramines hadn't occurred. The correlations show only that there is no correlation. It is misleading even to plot the lines.		Page 58
1st paragraph. It is stated that isolated instances of nitrification were found, then it is said that nitrification hasn't been documented. These contradict each other.		Page 59
Figure 32. There is a floating piece of text (no data) that needs to be moved.		Page 60
The issue of lead levels in the lead profile results from the mains are as discussed regarding p. 29. Lead levels in samples nominally from the main that are consistently above 10 ug/L are pretty important.		Page 61-62
Last Paragraph. The comparisons can and should be based on the amounts of lead contributed by the three source areas, rather than on this computed concentration		Page 62
Galvanic corrosion. The work done by Reiber and Dufresne needs more description of what they did experimentally and what they measured. For example the flow direction in the pipes in Figure 34 should be indicated.		Page 63
I recall that Marc Edwards talked about a different galvanic corrosion process, namely the deposition of copper and the oxidation of lead, when part of a LSL was replaced with copper tubing. Should this mechanism be discussed?		
Grounding currents. Again, explanation of what Reiber and Dufresne did is needed to accept that there was no impact on internal corrosion. Some explanation of why this conclusion is opposite the statement in the first sentence, namely that currents have been implicated in metal release.		Page 65

Peer Review of "Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events"

REVIEWER COMMENTS

Reviewer #1

EPA Question	Reviewer Comments	Reference (Page in Document)
Potential Causative Events		
a) 1. Does the study consider potential causative events that are appropriate? a) 2. Are the causative events and factors considered all relevant to the purpose of the study? a) 3. What additional causative events or factors, if any, should be considered?	This is the first occasion where ORP changes are invoked as a causative factor. I'd like to raise several points that the authors should consider. First, the thermodynamic oxidation reduction potential is probably hardly changed at all when free chlorine is replaced with chloramines. The E_H values computed for the pH, ammonia, chloride, and chlorine concentrations are almost the same. The "oxidation state" of the water really isn't different. Second, the measured ORP reflects the contribution of all redox couples in the water, with each having a thermodynamic potential and highly variable reaction kinetics at the measuring electrode surface. The differences in measured ORP values when chloramines are used instead of chlorine reflect the kinetics of reaction of chloramine at the surface, more so than a change in the oxidation reduction potential. Thus, it seems likely that chloramine isn't reactive enough to influence lead oxidation very much. It is just good luck that chloramine also isn't reactive enough to influence the measured ORP very much, either. **The argument should be restated to avoid the implication that the oxidation potential is lower with chloramine.**	
	The evidence seems to clearly indicate that the LSLs contained higher lead concentrations after the pH drop and switch to chloramination. This leads us to think that PbO_2 reduction must be a source of the lead. We can agree that free chlorine can cause PbO_2 to form and to keep it stable, but what is reducing the PbO_2 in the presence of chloramine? **This is a big hole in the argument about causation. There doesn't seem to be any evidence that pertains to the substance that is being oxidized when PbO_2 is being reduced.**	
Data Relevance		
b) 1. Does the study consider each causative event adequately?	No specific comments. See general comments.	
b) 2. Is the data presented all relevant to the purpose of the study?	No specific comments. See general comments.	
Data Analyses and Conclusions		
c) 1. Do the data and analyses support the conclusions? c) 2. Are there additional analyses that could better support the conclusions? c) 3. What additional conclusions, if any, can be reached based on the data and analyses?	The principal conclusions, that formation of PbO_2 was formed during use of free chlorine, that the change to chloramine and reduction of allowable pH in the distribution system, and that lead service lines are the predominant source of the lead, are reasonable and plausible. The report also does a good job of looking at a range of factors that do not seem to have a major role.	

Peer Review of "Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events"

REVIEWER COMMENTS

Reviewer #1

EPA Question	Reviewer Comments	Reference (Page in Document)
Follow-on Work		
d) 1. Section 6 of the study identifies possible follow-on work based on available findings and conclusions drawn from the study. Which, if any, of the recommended follow-on work should EPA undertake? d) 2. What additional follow-on work and/or research should EPA undertake as a result of this study?	I like the idea of using a GIS system to look for correlations in the data. However, it may well turn out that there really isn't enough data to see strong relations and, further, that the distribution of the LSLs in the system may obscure some water quality or treatment correlations that may be important. I also agree that more needs to be known about the impact of orthophosphate in this complex system and that more research is needed to really understand the mechanism of Pb (IV) formation and reduction.	

Peer Review of “Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events”

REVIEWER COMMENTS

Reviewer #2

EPA Question	Reviewer Response	Reference (Page in document)
General Comments		
	In terms of “simultaneous compliance” issues, additional discussion should be included on the significant emphasis by DCWASA on “solving” TCR related problems in the distribution system being a major factor in subsequent decisions and events.	
	Figure 18. Check the Y-axis title (should it also state 90th percentile in addition to average?).	Figure 18
	Figure 19. The note stating “average (Pb) level before chloramines = 5 ug/L” is misleading since this only considers data from July 1997 to the time of the conversion. The true “average” Pb level “before chloramines” (i.e., considering all of the data) I suspect might be greater than 5 ppb.	Figure 19
Potential Causative Events		
a) 1. Does the study consider potential causative events that are appropriate?	Yes.	
a) 2. Are the causative events and factors considered all relevant to the purpose of the study?	I would not consider “Lead Released from Piping Systems/Lead Service Lines” (Sections 1.3.1 and 5.1) to be a causative factor in and of itself. For example, if CCT had been optimized (before or after conversion to chloramine), then lead release would not have happened on its own. I would consider this a resultant outcome of the other causative events/factors but not a contributing factor per se.	Sections 1.31 & 5.1
a) 3. What additional causative events or factors, if any, should be considered?	My understanding is that WA made other treatment changes at or around the time of chloramine conversion. One such change included the type of alum used (from dry alum to liquid alum) and also attempts (over the years) to gain better “control” of the aluminum coagulation process. Snoeyink (2003) has noted possible protective or detrimental effects of aluminum-containing scales on Pb release. Another treatment change was WA’s implementation of enhanced coagulation practices, which might be associated with increased residual aluminum concentrations.	

Peer Review of "Elevated Lead in D.C. Drinking Water – A Study of Potential Causative Events"

REVIEWER COMMENTS

Reviewer #2

EPA Question	Reviewer Response	Reference (Page in document)
Data Relevance		
b) 1. Does the study consider each causative event adequately?	For "Lead Released from Lead Service Lines" (Section 1.3.1) the report states "Given that many service lines in the DCWASA distribution system are made of lead, this source is a major cause of high lead levels." Along similar lines to the comment in (a) 2. above, the presence of (many or some) lead service lines does not <u>cause</u> high lead levels.	Section 1.3.1
	Table 1 (Summary of Causative Factors for High Lead Levels) – I would disagree with the "medium" contribution assigned to this item. Based on the data presented in the remainder of the report as well as "conventional" Pb (II) theory, the improper corrosion control treatment in place prior to or simultaneous with the conversion to chloramine is as "equal" a contributor to the high lead levels seen after chloramine conversion. Had CCT been optimized (e.g., using an orthophosphate inhibitor), it is unlikely that the lead release would have been of the same magnitude. In fact, Section 5.3.2 states that the OCCT pH may have been "too low of a pH for maintaining Pb (II) scales under chloramine conditions." The OCCT designated in February 2000 and subsequent designation of OWQPs, and the OCCT designated in May 2002 (retroactive to July 2000) were inappropriate.	Section 5.3.2
	Distribution System pH Levels and pH Variations (Section 1.3.3 and elsewhere) – At a pH of 7.0, 90th percentile Pb levels should not have been <15 ppb, in turn, raising a flag that the CCT mechanism wasn't what it appeared to be. Such explanation as to how 90th Percentile Pb levels were being maintained below the 15 ppb Action Level despite lower-than-optimal pH for Pb (II) passivation might have led to awareness that other factors needed to be considered related to the chloramine conversion. This type of discussion should be included in this section as well as in related paragraphs in Section 4 and highlighted as a "reality check" on theoretical models. There is some discussion toward this end in Section 5.2.7 (4th paragraph) but this linkage should also be carried into the sections discussing (inadequate) pH levels.	Section 1.3.3 Section 5.2.7
b) 2. Is the data presented all relevant to the purpose of the study?	Chlorine burn data (e.g., Table 8 in Section 5.2.3) – discussion should be added as to the likelihood (in theory) that Pb levels are/can be impacted in the relatively brief time period of a Cl2 burn. What is the theory to explain the kinetics/reaction rates for this? Perhaps this is an item to consider under future research needs? Can, in theory, such a change affect Pb levels that quickly? (one month)	Table 8, Section 5.2.3
Data Analyses and Conclusions		
c) 1. Do the data and analyses support the conclusions?	Yes, with the exception of comments noted in (c) 3 below relative to the "significance" of the inadequate (too low) pH.	Figure 19

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REVIEWER COMMENTS

Reviewer #2

EPA Question	Reviewer Response	Reference (Page in document)
c) 2. Are there additional analyses that could better support the conclusions?	Section 4.2.2 – Data for Pb at the "Point-of Entry" (POE) should be presented and discussed rather than reliance on sampling from the distribution system mains to infer POE levels. In addition, the report defines "source water" as raw water from the Potomac River. This is confusing with respect to conventional terminology used in the LCR and various guidance documents in which a "source water sample" is defined as "A sample collected at entry point(s) to the distribution system representative of each source of supply after treatment."	Section 4.2.2
	Section 5.8 Drought Conditions and Effects on Corrosivity of DCWASA Water – One consideration is whether drought conditions may have affected the nature of the natural organic matter (NOM) in a manner than affected the chlorine demand of the finished water, in turn affecting ORP, etc.	Section 5.8
c) 3. What additional conclusions, if any, can be reached based on the data and analyses?	As noted in Comment (b) 1, I disagree with the "medium" contribution assigned to the "distribution system pH levels and pH variations" factor as presented in the Table 1 (Summary of Causative Factors for High Lead Levels). Based on the data presented in the remainder of the report as well as "conventional" Pb (II) theory, the improper corrosion control treatment in place prior to or simultaneous with the conversion to chloramine is as "equal" a contributor to the high lead levels seen after chloramine conversion.	Table 1
Follow-on Work		
d) 1. Section 6 of the study identifies possible follow-on work based on available findings and conclusions drawn from the study. Which, if any, of the recommended follow-on work should EPA undertake?	Pb (IV) as a corrosion control treatment mechanism needs much greater understanding and research, including under what conditions/factors does Pb (IV) form, remain stable, etc. The effects of orthophosphate addition under various ORP conditions are also important to understand (e.g., for various system changes, can orthophosphate bind soluble lead to keep up with the rate of Pb release from existing scales that may break down).	
d) 2. What additional follow-on work and/or research should EPA undertake as a result of this study?	Fundamental research in Pb (IV) is needed. Some examples include: defining threshold ORP levels to maintain protective scales; determining the feasibility of converting Pb (IV) scales to some possible new Pb orthophosphate compounds; etc.	
	As noted above, the impact of chlorine burn on Pb solubility (and reaction kinetics thereof in short periods of time in which such switches generally take place) would also be of significant interest to utilities.	

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REVIEWER COMMENTS

Reviewer #3

EPA Question	Reviewer Comment/Response	Reference (Page in document)
General Comments		
	Given the prevalence and importance of chloramination for many water utilities, it is important that the casual reader does not directly link chloramination with lead problems. While the Washington, DC lead problems are an important “lesson learned”, the Executive Summary and Report should emphasis that the problem resulted from a “perfect storm” (historical high chlorine dosage, presence of lead scales and lead service lines, poor pH control, and chloramination). One or two of these occurrences, in isolation, may not have resulted in the problem. The data and conclusions presented in Section 5.2.6 should be emphasized and be presented in the format that can be easily understood by the typically water utility professional.	Section 5.2.6
	I also have a concern with how the sources of lead were characterized between the faucet, in-house plumbing, lead service line and distribution system (example p.29 and 30). While the text states that the lead service lines were the primary source of lead and no or limited lead should be present in the distribution system (water mains prior to meter and service line), several of the figures do not support this conclusion. The engaged reader should understand that the “distribution samples” are pulled through the lead service lines and in-house plumbing, and are not indicative of distribution system water quality. However, the casual reader might draw the wrong conclusion. Therefore, I would consider either removing the data from the graphs or footnoting why there was a presence of lead in the distribution system samples. Question - Was any direct sampling/lead analysis done from the distribution system during the study period? Also, was only lead sampling done at locations without lead service lines?	Page 29 & 30
	Additionally, the author frequently reference that the lead service lines are part of the distribution system (p.72 and other references). Most utilities do not consider service lines part of the distribution system.	Page 72
Potential Causative Events		
a) 1. Does the study consider potential causative events that are appropriate?	Yes. The study considers all of the classic causative events for lead corrosion (pH, redox, temperature, etc) and adequately explains how these events interact to cause the lead problems. However, given the variability in pH, conductivity, temperature, total chlorine, etc., the reader is not convinced that the original Optimal Corrosion Control Treatment (OCCT) guidelines were correct. This issue is important because the study does not establish that lead control was effective prior to the chloramine conversion. In addition to the change in pH levels, the variability in other OCCT parameters and lead sampling results suggest that lead control was questionable even prior to the chloramine conversion. As shown in Figure 17, the set of the three data points (red triangles) with lead levels ranging between 100 and 150 µg/L, on or before the conversion to chloramines, indicate that lead control was already questionable prior to chloramine conversion.	

REVIEWER COMMENTS

Reviewer #3

EPA Question	Reviewer Comment/Response	Reference (Page in document)
a) 1. continued	Also, the process for setting the current OCCT has not been described (page 71) and it is not clear that the new parameters (when orthophosphate is applied) are appropriate. Given the large variability seen in the water quality parameters (page 13) it is not clear how the pH 7.7±0.3 is appropriate or will be consistently achieved.	Page 71 Page 13
a) 2. Are the causative events and factors considered all relevant to the purpose of the study?	In general, yes. However, the potential causative effects parameters such as conductivity and temperature need to have their role better described in the report. For example, are these parameters important because they are used in the calculation of corrosion indexes or impact lead solubility?	
a) 3. What additional causative events or factors, if any, should be considered?	The study needs to de-emphasize individual causative factors and focus more on the chain of events. A chart with a timeline dating back to 1990 would be useful to help understand the entire situation. Included in the chart/timeline should be a description of key decisions, 90th percentile lead levels, shifts in pH and chlorine, coliform events, and DBP values. There is a need to place more emphasis on the fact that corrosion control was an issue prior to the chloramine conversion and question whether the OCCT/OWQP was appropriate. In the Appendix (pA-20) is a timeline of the OCCT decisions. A better summary of the reasoning behind the decisions would be helpful.	Page A-20
	The decision to drop the allowable distribution system pH from 7.7 to 7.0 is not emphasized strongly enough as a causative factor. Running a system at pH 7.0 with no phosphate and lead service lines is a poor operating decision. Change in pH occurred in July 1, 2000. Conversion to chloramines occurred November 2000. Average 1st draw lead samples increased between December 1999 and November 2000. Second- draw samples were greater than 15ppb in the July – September monitoring period. It is unlikely that the change to chloramines could have solubilized the lead (IV) so quickly. It may not be possible to ascertain whether the change in pH directly resulted in lead release or if it affected existing scales to allow the chloramine to solubilize the lead (IV).	
	Additionally, it is possible that drought conditions increased the levels of sulfate and/or chlorine in the water. The lack of these data does not exclude the role of the drought on lead corrosion. Potentially, chloride and sulfate information from other nearby utilities (Fairfax) could be used in this assessment.	

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REVIEWER COMMENTS

Reviewer #3

EPA Question	Reviewer Comment/Response	Reference (Page in document)
Data Relevance		
b) 1. Does the study consider each causative event adequately?	In general, yes. However, as previously stated, more focus needs to be on the pre-existing conditions prior to chloramination. Specifically more emphasis needs to be placed on pH. For example, I believe that the "Distribution system pH levels and pH variations" listed in Table 1 should have a "High" rating for its "Relative Contribution to High Lead Levels' especially since p.53 states, "varying ph levels can significantly affect the formation of protective scales on the interior of the pipes and the capability of the system to maintain those scales in a stable form".	Table 1 & Page 53
	Washington, DC had a unique combination of factors contributing to their lead problems. USEPA allowed Washington, DC more flexibility in their treatment during the 1990s than would be allowed by most States. Appendix A summarizes the feasibility studies performed in 1998 to analyze various post treatments schemes. While I believe it would be difficult to include a statement in the Report, it would be interesting to know whether it was an economic decision that led to the poor pH control and lead corrosion prior to chloramination.	Appendix A
	In the section on the sanitary surveys (p20) the last line states "it is unlikely that findings from these sanitary surveys had any influence on tap lead levels". However, only results from sanitary surveys from 1999 onward are presented. A big question is – did earlier deficiencies lead to the coliform issues which in turn led to the decision to go to higher chlorine levels? I agree that it is unlikely that it was the prime causative event, but it may have resulted in a cascade of events.	Page 20
b) 2. Is the data presented all relevant to the purpose of the study?	Yes. However, I would spend less time focusing on the "chlorine burn" issue. See response to question **c) 1**.	See Q. c) 1.
Data Analyses and Conclusions		
c) 1. Do the data and analyses support the conclusions?	In general, yes. However, I have issues with the entire analyses associated with the "chlorine burn". For example, the data in Figure 19 shows considerable variability in monthly lead levels. Although the two dates when the "chlorine burn" occurs show dips in average lead levels, there are other examples of low average lead levels when chloramines were used (Feb 03, Jan 04, Jul 04). This variability in lead levels makes it impossible to conclude that the conversion back to chlorine had any statistically significant reduction in lead. The dips in lead levels during the chlorine burn are not distinguishable from the normal variability in lead levels.	Figure 19

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REVIEWER COMMENTS

Reviewer #3

EPA Question	Reviewer Comment/Response	Reference (Page in document)
c) 1. continued	On page 39, paragraph 4, there is no statistical analysis to suggest that 8 of 12 sites with elevated lead levels were different from 5 of 12 sites. On page 40, the report suggests that a monthly average of 28 µg/L is different from 17 µg/L which is different from 37 µg/L. However, the statistical analysis provided does not support this statement. Application of a t-test for these data is inaccurate since these are not paired data. A nonparametric test (Wilcoxon) would be more appropriate. Given the highly variable results for lead, it is not clear that these differences are meaningful. If the data from the 4th High Pressure Zone was removed (orthophosphate treatment) would the data have been more conclusive?	Page 39 & 40
	As shown in Figure 21, if analytical inconsistencies could account for a difference between 1 and 6 µg/L of lead, then how can the report conclude that small variations between the "chlorine burn" and "chloramine" lead data be significant. Again, interpretation of the data has been performed using only "eyeball" statistics.	Figure 21
	Finally, the term "chlorine burn" is poor and misleading.	
c) 2. Are there additional analyses that could better support the conclusions?	The author might consider calculating various corrosion indexes under variable water quality conditions in assessing the corrosion potential before and after chloramine conversion.	
c) 3. What additional conclusions, if any, can be reached based on the data and analyses?	I believe the author reached many proper conclusions during his analysis of the data. However, the Washington, DC lead occurrences must be put in the proper prospective. The conclusions need to emphasize the pre-existing conditions in the Washington, DC system prior to chloramination and the other numerous factors that contributed to the lead problems post chloramination. The author needs to continually emphasize that other water utilities need to fully understand the combination of factors in the Washington, DC system before relating this experience to the operation of their system.	
Follow-on Work		
d) 1. Section 6 of the study identifies possible follow-on work based on available findings and conclusions drawn from the study. Which, if any, of the recommended follow-on work should EPA undertake?	I believe the proposed DCWASA-related follow on evaluation would have limited value. It is general knowledge that lead service lines are a (the) primary source of lead in drinking water. I am not convinced that the proposed geographic information system work (GIS) to plot the sampling data and other water quality characteristics in the distribution system between before and after the LCR monitoring period will provide valuable information. Given the variability in the water quality throughout the distribution system and the variability of lead levels at individual sampling locations, I am not convinced that any additional good correlation will be derived. Also, if this study is performed, I am not also convinced that a sophisticated GIS system is needed to complete the study.	

REVIEWER COMMENTS

Reviewer #3

EPA Question	Reviewer Comment/Response	Reference (Page in document)
d) 2. What additional follow-on work and/or research should EPA undertake as a result of this study?	There are several areas of follow-up work/research that might be valuable: • Additional research can be performed to define ORP conditions under different chlorine and chloramination conditions/residuals. For example, would lower free chlorine residuals in the Washington, DC system reduce the Pb (IV) formation and the problems with chloramine conversion? • Additional knowledge is needed on the impact the treatment changes on scale formation and solubility of trivalent lead? • Utilities should develop a better understanding of the impact of lead service lines replacement (especially partially replacement) on compliance and lead levels. Specifically, is there any value in doing partial lead service line replacement or would this action have a tendency to negatively impact on compliance? • Research could be performed to determine the impact of meter life on lead concentrations in drinking water. • Given the presence of particulate lead in the Washington, DC samples and the relatively small health effects associated with particular lead, the overall importance of particular lead in the regulatory compliance strategy should be investigated and possibly reconsidered.	