



Aaron Yeow, M.P.H.  
U.S. Environmental Protection Agency (U.S. EPA) Science Advisory Board (SAB)  
1200 Pennsylvania Avenue, NW, (1400R)  
Washington, DC 20460

April 27, 2011

Re: Marc Edwards Submission to EPA SAB on the Issue of Partial Pipe Replacement

Dear Aaron,

Attached are documents that might be useful to the EPA SAB in their consideration of partial pipe replacements including the following:

- 1) Marc Edwards Conflict of Interest Statement (pages 1-3)
- 2) "Flawed Science Begets Flawed Policy" Lambrinidou/Edwards (pages 4-16)
- 3) 1997 E-mail of Mike Schock (produced by Freedom of Information Act) pages 17-18
- 4) Excerpt of Edwards' 2004 Congressional Testimony (pages 19-20)
- 5) Exemplary notarized letter sent from Marc Edwards to EPA in early 2004 (page 21-27)
- 6) No pages 28-38: Copyright permission not obtained.
- 8) Exemplary Use of Reiber Report to Congress, April 2008 (39)
- 9) Edwards Critique of the Reiber and Dufresne Study May 2008, with background information derived from Marc Edwards Freedom of Information Act Request (pages 40-68)
- 10) Nguyen et al., 2009 WQTC presentation. (pages 69-77)
- 11) Nguyen et al., 2010 Webcast slides. (pages 78-95)
- 12) No pages 96-137: Copyright permission not obtained.
- 13) Cartier et al., 2011. Poster: Effect of Flow Rate and Lead/Copper Pipe Sequence and Junction Types on Galvanic and Deposition Corrosion of Lead Pipe (page 138)
- 14) Triantafyllidou et al., Lead (Pb) in Tap Water and in Blood: A Critical Review (139-194)
- 15) Edwards' Comment on Brown et. al, 2010 (195)
- 16) Excerpt of Edwards Congressional Testimony 2011 (pages 196-198)

My phone is (540) 231-7236 if you should have questions about this submission.

Marc Edwards

Charles Lunsford Professor of Civil Engineering  
Virginia Tech

## **Conflict of Interest Statement: Partial Pipe Replacements. Marc Edwards-Virginia Tech**

Dr. Marc Edwards has been outspoken against partial pipe replacements as they are currently practiced under the EPA Lead and Copper Rule. He gave testimony to Congress in 2004 indicating that his experiments showed that the practice sometimes created spikes of lead in water, posed a serious public health hazard, and requesting that the practice be banned in Washington D.C. until the EPA proved that partial replacements were beneficial. Several notarized letters outlining his concerns were sent to appropriate authorities in 2004. The practice was banned temporarily in 2004.

After a study (Wujek et al, 2004) claimed that lead spikes did not occur in Washington D.C. after partial replacements, and allegedly contradicting research of Dr. Edwards and other investigators, the partial pipe replacements were resumed. Alarmed at spikes of lead that he later personally measured after partial replacements in Washington D.C. homes, Dr. Edwards conducted a Freedom of Information Act (FOIA) request of EPA RIII in 2005, 2006 and 2007 related to partial replacements in Washington DC, and to examine the scientific evidence for EPA RIII public claims that lead spikes did not occur after partial pipe replacements. The FOIAs revealed that the Wujek study was actually conducted in a brief period of time in which chloramine was not present in the water, but free chlorine was. It was perfectly obvious to EPA RIII and their consultants that free chlorine inhibited lead corrosion, and their e-mails acknowledge that the purported "benefits" from partial replacements described in Wujek et al. 2004 were probably due to the presence of chlorine. On the basis of Dr. Edwards' work, and after reporters began to question EPA RIII on this issue, this critical omission was finally acknowledged 6 years after the study was conducted (<http://www.epa.gov/dclead/links.htm>):

**Note (March 2010):** The Wujek (2004) paper discussed in section 2.5.3 does not mention that the post-partial replacement samples were collected during a temporary free chlorine treatment period, a treatment regime associated with lower lead levels.

Dr. Edwards conducted a FOIA with Dr. Yanna Lambrinidou (Founder, Parents for Non-Toxic Alternatives) of the DC Department of Health in 2007, which revealed that a high percentage of Washington D.C. children with lead-poisoning lived in homes with partially replaced pipes.

Dr. Edwards' FOIAs further revealed that EPA RIII and DC WASA had sampling data since late 2004, indicating lead spikes did occur after partial replacements, contradicting their prior public statements. In more than a dozen samples the lead spikes measured by the utility (and reported to EPA RIII) after partial pipe replacements exceeded 5,000 ppb lead. Dr. Edwards presented information about these spikes in testimony to the D.C. Council on this issue in 2008. That testimony helped stop partial pipe replacements in Washington D.C., although they still occur in some cases.

Dr. Edwards also determined that a DC WASA employee (Rich Giani) was mistaken about DC WASA's practices related to partial pipe replacement. Specifically, for more than 4 years, Mr. Giani repeatedly stated that DC WASA had always used a dielectric during partial pipe replacements. This fact would imply that Dr. Edwards' concerns about galvanic

corrosion at Washington, D.C. homes were without basis, and cast into doubt results of his voluntary sampling in homes of D.C. residents which showed long-term problems associated with the practice. Mr. Giani's mistaken assertions about the utility's use of dielectrics appeared in a later EPA RIII report written by Dr. Steve Reiber (Reiber and Dufresne, 2006). After years of investigation on the issue by Dr. Edwards, including trips to personally observe partial replacements that did not use a dielectric in Washington D.C., DC WASA and EPA RIII eventually acknowledged that dielectrics had never been used for partial replacements. EPA RIII published a correction on this issue (<http://www.epa.gov/dclead/links.htm>).

Dr. Edwards has also conducted a FOIA for documents related to the above EPA RIII study (Reiber and Dufresne, 2006), which contradicted decades of prior research, and claimed that even in the worst case galvanic corrosion from partial pipe replacements had inconsequential impacts on lead in water. The study further claimed that partial pipe replacements in Washington, D.C. were part of an effective program to reduce lead in water, and the D.C. lead pipe replacement program was presented as the "Solution" to lead in water and utility liability associated with lead service lines. The Reiber et al. document has repeatedly been given to the U.S. Congress and other entities by the U.S. EPA, as "proof" that galvanic corrosion is insignificant. Other utilities in the U.S. and around the world have cited this document to support their own partial pipe replacement programs. After years of failed attempts to convince EPA RIII and Dr. Reiber to acknowledge limitations of the Reiber et al. study and to publish appropriate caveats (including several attempts before the final report was even written), Dr. Edwards grew concerned about how the report was repeatedly used in a manner that downplayed legitimate health concerns. Dr. Edwards then wrote a letter to the *DC WASA Ad Hoc Committee on Drinking Water Quality* documenting numerous scientific concerns about Reiber et al.. In that report Dr. Edwards characterized the EPA RIII study by Dr. Reiber as a "third rate hack job," and highlighted issues with the studies approach, methods and conclusions. Dr. Edwards has given, and will continue to give, public presentations in which he cites this report, as an exemplar of unethical science and engineering. To date, EPA RIII and Dr. Reiber have refused to acknowledge, in writing, many of the obvious limitations and errors in the report.

Dr. Edwards also reported on his work to Congressional Investigators, which helped prompt an investigation of the U.S. Centers for Disease Control (CDC) and Prevention, related to their studies of health effects associated with high lead in Washington, D.C.'s drinking water. The congressional investigation revealed that the CDC knew about higher incidence of lead-poisoning of D.C. children living in homes in which pipes had been partially replaced-- information that the CDC did not publicly acknowledge until issuing a health alert in 2010. Aspects of Dr. Edwards' work on this issue are described his sworn testimony to Congress in May of 2010 and in a related Congressional Report. Under severe criticism for their actions, the CDC later wrote a peer reviewed paper in which they stated that partial pipe replacements did not significantly increase the likelihood of elevated blood lead in Washington D.C. children relative to that observed in homes with intact lead service lines (Brown, M.J., et al., 2011), even though there was a higher likelihood of elevated blood lead in children living in homes with partial pipe replacements (confidence did not exceed 95%). Unfortunately, the Brown et al. report did not use data for several hundred partial pipe replacements that were conducted before corrosion control was implemented by DC WASA. Dr. Edwards has written a comment to the journal that published the CDC paper, asking that CDC acknowledge this fact, and requesting a new statistical analysis using all the available data.

During an EPA public meeting on potential revisions to the lead and copper rule October 2008, and despite previously acknowledging the study was fatally flawed, the EPA and their consultants once again tried to present the Wujek et al. 2004 study as evidence that partial replacements reduced lead in water. Yet again, the EPA and their consultants did not mention that chlorine was in the water. Dr. Edwards once again criticized the use of the study in this manner. In response to a FOIA, EPA RIII later acknowledged that they had no data to demonstrate benefits of partial pipe replacements in reducing lead in water.

Dr. Edwards has repeatedly stated that he believes there are instances in which galvanic corrosion does not cause problems, instances where galvanic corrosion does cause problems, and is committed to doing sound fundamental research to better understand the potential benefits and hazards of partial pipe replacements. He is currently collaborating with several researchers and utilities who are attempting to advance fundamental understanding of this issue. He is presenting several articles on this subject at the 2011 AWWA Conference in Washington D.C. and is advising graduate students who are conducting research on this subject. The work to date has conclusively demonstrated that galvanic corrosion is sometimes a long-term concern, consistent with decades of prior research on the subject. Dr. Edwards has also written a paper on galvanic corrosion during partial service line replacements with Simoni Triantafyllidou, parts of which were presented at AWWA National Conferences and which is under review in Journal AWWA. Several other peer reviewed papers are in progress.

Dr. Edwards was recently awarded a grant from the Robert Wood Johnson Foundation along with investigators from Northeastern University, EPA and Parents for Nontoxic Alternatives to study the issue of partial pipe replacements and conduct a cost benefit analysis. That work is underway, and involves collaboration with DC WASA, EPA, and a Providence water utility. Dr. Edwards is also collaborating with Canadian researchers who are studying impacts of partial pipe replacements on lead in water. He is co-advising a Canadian researcher who is conducting his PhD work on the subject and hosted the student in his lab at Virginia Tech where he worked on a large scale pilot rig of partial pipe replacements.

Dr. Edwards was asked to serve as an expert witness in a lawsuit served on behalf of lead poisoned children in Washington D.C.. He has refused to participate as a paid expert in any lawsuit related to health impacts of elevated lead on DC children, but his testimony has been subpoenaed. Some of these lawsuits may address lead poisoning of Washington D.C. children which occurred as a result of partial pipe replacements.

As a final point, this disclosure does not reveal every publication, presentation and public statement by Dr. Edwards on the issue of partial pipe replacements, nor does it reflect on every negative public comment he has made regarding the behavior of EPA, DC WASA and their consultants in relation to this issue.

APHA 138<sup>th</sup> Annual Meeting & Expo  
November 6-10, 2010  
Denver, CO

## Flawed science begets flawed policy

EPA's Lead and Copper Rule, partial lead service line replacement, and elevated blood lead levels among children

Yanna Lambrinidou, PhD, Parents for Nontoxic Alternatives, Washington, DC  
Marc Edwards, PhD, Virginia Tech, Blacksburg, VA  
Simoni Triantafyllidou, PhD Candidate, Virginia Tech, Blacksburg, VA

1

### Presenter Disclosures

The following personal financial relationships with commercial interests relevant to this presentation existed during the past 12 months:

**No relationships to disclose**

2

### Outline

1. Why is lead in drinking water a health concern?
2. EPA's Lead and Copper Rule (LCR) of 1991
3. Washington, DC 2001-2004: lead-in-water crisis
4. 2004 and 2006 PLSLR studies
5. CDC's 2010 announcement about analysis of Washington, DC data
6. Where is the science on PLSLR today?
7. Social justice: policy and practice

3

1. Why is lead in drinking water a health concern?

4

- **312 BC:** Romans note high death rate of slaves involved in production of lead drinking-water pipe
- **2<sup>nd</sup> century BC:** "Lead makes the mind give way"

Dioscorides, ancient Greek physician, pharmacologist, and botanist



Image source: [http://upload.wikimedia.org/wikipedia/commons/3/36/Lead\\_pipe\\_-\\_Bath\\_Roman\\_Baths.jpg](http://upload.wikimedia.org/wikipedia/commons/3/36/Lead_pipe_-_Bath_Roman_Baths.jpg)

5



"...water ought by no means to be conducted in lead pipes, if we want to have it wholesome."

Vitruvius (80-70 BC - c. 15 BC), Roman architect and engineer, in *De architectura*, Book VIII

Image source: <http://upload.wikimedia.org/wikipedia/commons/a/a3/Vitruvius.jpg>

6

**November 30, 1855**  
*New York Daily Times*  
**“Iron and Lead Pipes for Carrying Water”**

“Lead pipe is more conveniently laid down, as it is easily bent around large stones, and to fit any irregularities in the soil.

Everything considered, **lead pipe is to be preferred to iron for conveying water or gases under ground**, even when it is required to be of such size and thickness that the first cost will be considerably higher.”



Image source: <http://www.newmexicohistory.org/filedetails.php?fileID=1340>

7

- Around 1900, **>80% of large US cities used lead service lines (LSLs)**, especially in the Northeast and Midwest
- In the late 1800s-early 1900s, journal articles and reports from Great Britain and the US began to document **lead poisonings from drinking water**
- By the 1920s, many US cities and states had begun **revising plumbing codes** to ban or limit the use of LSLs.

Troesken, 2006, *The Great Lead Water Pipe Disaster*  
 Rabin, 2008, “The Lead Industry and Lead Water Pipes,” *American Journal of Public Health*.



**Lead helps to guard your health**

**YOU** wouldn't live today in a house without an adequate plumbing system. For without modern plumbing, sickness might endanger your life.

Lead concealed in the walls and under the floors of many modern buildings helps to give the best sanitation.

In some cities today the law specifies that lead pipe alone may be used to bring water from street mains into the building.

**NATIONAL LEAD COMPANY**  
 121 East 34th St., New York, N.Y. 10018

Edited from ad in National Geographic 11/1923

9

- **Promotional campaigns** by the lead industry continued until the 1970s
- The **plumbing codes** of large US cities like Boston, Milwaukee, San Diego, Philadelphia, Denver, and Chicago **called for LSLs well into the 20<sup>th</sup> century**, and the 3 **national model plumbing codes allowed** the use of LSLs until the 1970s and 1980s
- It is believed that approximately **3.3-6.4 million LSLs** were installed
- **In some cities (e.g., Chicago), LSLs were required until 1986**, when Congress passed the “Lead Ban” that prohibited the use of LSLs

Rabin, 2008, “The Lead Industry and Lead Water Pipes,” *American Journal of Public Health*.  
 AWWA, 1996, “Lead Service Line Replacement: A Benefit-to-Cost Analysis.”  
 Troesken, 2005, “Historical Predictions,” Unpublished paper.  
 Renner, 2010, “Reaction to the Solution,” *Environmental Health Perspectives*.

10

Lead service line

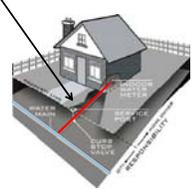
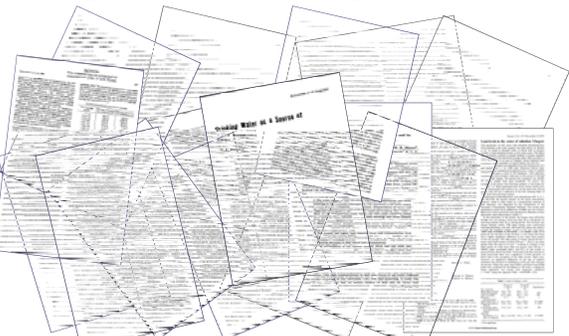
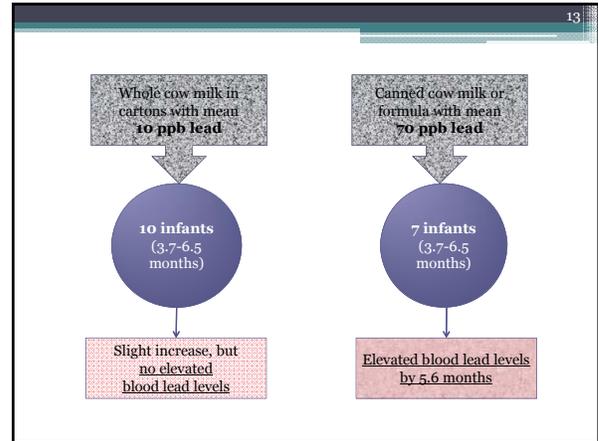
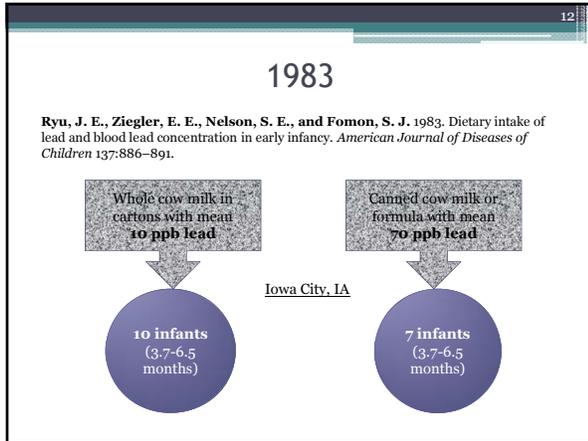


Image source: [http://www.ottawa.ca/residents/water/wq/facts/lead\\_water/lppp\\_brochure\\_en.html](http://www.ottawa.ca/residents/water/wq/facts/lead_water/lppp_brochure_en.html)

11

Surge of studies starting in the 1960s





14

Study	Year	Location
<b>Pocock, S. J., et al.</b> , <i>Journal of Epidemiology and Community Health</i>	1983	Britain
<b>Sherlock, J. C., et al.</b> , <i>Human Toxicology</i>	1984	Scotland
<b>Elwood, P. C., et al.</b> , <i>Nature</i>	1984	Cardiff
<b>Lacey, R., et al.</b> , <i>Science of the Total Environment</i>	1985	Glasgow
<b>Bonnefoy, X., et al.</b> , <i>Water Research</i>	1985	France
<b>Raab, G. M., et al.</b> , <i>Environmental Geochemistry &amp; Health</i>	1987	Edinburgh
<b>Shannon, M. and J. W. Graef.</b> <i>Clinical Pediatrics</i>	1989	Boston
<b>Cosgrove, E. V., et al.</b> , <i>Journal of Environmental Health</i>	1989	Boston

15

Study	Year	Location
<b>Lockitch, G., et al.</b> , <i>Canadian Medical Association Journal</i>	1991	Vancouver
<b>Maes, E. F., et al.</b> , EPA Drinking Water Docket	1991	Hawaii

↓

Pocock, et al. 1983 and Lacey, et al. 1985, Maes, et al. 1991 were used by EPA to write the **Lead and Copper Rule (LCR) of 1991**

16

## 2. EPA's Lead and Copper Rule (LCR) of 1991

- 17
- Enacted to **protect the public from exposure to lead & copper at the tap**
  - "... the total drinking water contribution to overall lead levels may range from **as little as 5 percent to more than 50 percent of children's total lead exposure. Infants dependent on formula may receive more than 85 percent of their lead from drinking water.**"
- As exposures decline to sources of lead other than drinking water, such as gasoline and soldered food cans, drinking water will account for a larger proportion of total intake."
- (Federal Register, Vol. 56, No. 110, June 7, 1991, p. 26470)*

18

**The LCR requires water utilities to:**

- Treat drinking water in a way that minimizes its ability to corrode lead pipes 
- Monitor drinking water by capturing *worst-case* lead levels *at the tap* under normal water use conditions 

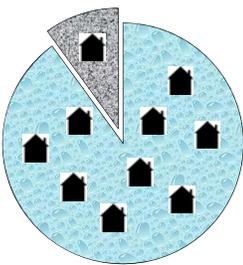
Image sources: <http://www.fags.org/photo-dict/phrase/715/water-treatment-plant.html>; <http://lijress.wordpress.com/tag/green/>

19

Standard	Designation	Enforceability
0 ppb	Maximum Contaminant Level Goal (MCLG)	Non-enforceable
15 ppb	Lead Action Level (LAL)	Enforceable

20

**The LCR allows up to 10% of tested homes to have taps that dispense any amount of lead.**



< LAL  
 > LAL

21

**Lead-in-water health guidance**

Organization	Lead (ppb)	Health Guidance
WHO*	10	Do Not Drink
CDC	15	Do Not Drink
EPA*	40	Imminent and Substantial Endangerment
EPA	5,000	Hazardous Waste

\* Also European Union (2013) and Canada  
# Posted on EPA website until March 2004

22



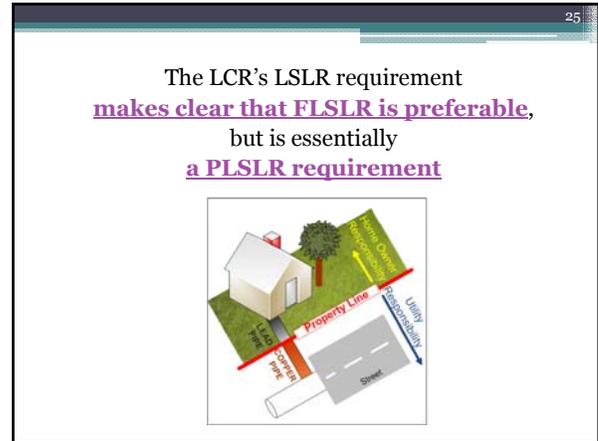
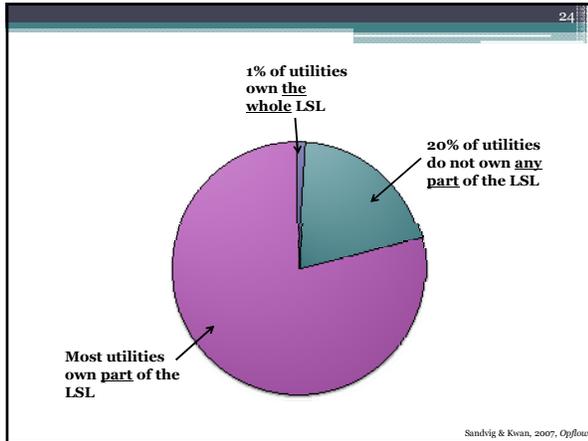
**If >10% of sampled homes test above the LCR's LAL of 15 ppb, water utilities are required to take additional measures:**

- Source water treatment
- Corrosion control optimization
- Public education
- **LSLR**

23

**The LSLR requirement mandates:**

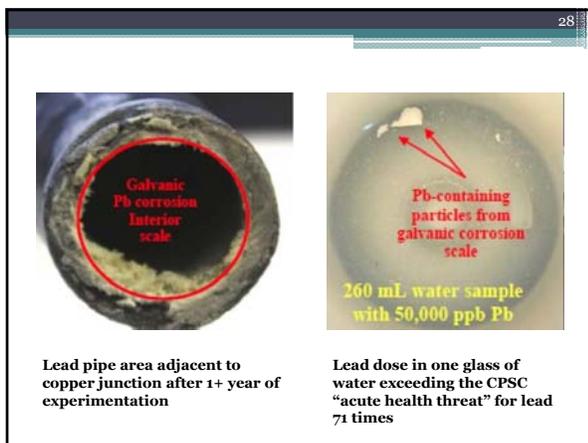
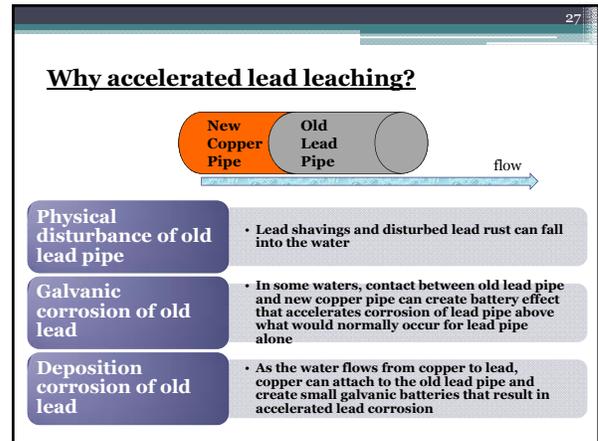
- Annual replacement of **7% of a water utility's total number of LSLs** with levels >15 ppb in 1<sup>st</sup> draw water
- **Replacement of the portion of the LSL that the water utility owns**



26

EPA was aware of potential PLSLR risks

- o **Studies going back to the mid-1800s** documented in some instances accelerated lead release *after* connecting lead pipe with other metals
- o Prior to 1991, **individual commentors had expressed concern about occasional increases in lead leaching after PLSLR**



29

Study	Finding	EPA's interpretation
Britton & Richards 1981	69 homes: Occasionally, <b>increased and erratic</b> lead levels observed. In some cases, <b>no low lead measurements</b> were obtained, despite satisfactory pH control.	Focused only on one case study in the paper that took place in a town with satisfactory pH control and rare lead-in-water problems. <b>Concluded that lead increases after PLSLR are only temporary</b> and can be minimized, if not prevented, when water corrosivity is optimally controlled. Asserted that corrosion control in this case was "poor" when in fact the authors note the opposite.
AWWA 1990	9 homes: <b>Temporary increases</b> (1-2 weeks) in lead levels after PLSLR <b>in chlorinated water</b>	<b>Concluded that increases are short-lived, but also acknowledged the presence of an "effective passivation film."</b> Did not raise questions about lead leaching in the absence of such film.
PA 1991c	4 homes: " <b>Very little change in lead levels ... and some increases</b> in some cases" <b>in chlorinated</b>	<b>Contended that the findings were not relevant</b> to the LCR because all pre-PLSLR values were below 15 ppb, and the LCR does not require LSLR in low lead homes.

30

**1991 EPA:**

- **PLSLR has benefits**
- **Removal of any amount of lead in plumbing reduces risk**
- **Any increases in lead-in-water levels will be temporary**, if they occur at all
- **Residents will be protected** because water utilities will tell them how to take temporary precautions

31

- **Commentors continued to express concern:** EPA has **no studies** showing that lead falls below the LAL after PLSLR in different waters and different water treatments.
- **1997 internal e-mail from EPA chemist:**

[T]he bottom line is that EPA is promulgating a policy that **KNOWINGLY INCREASES LEAD LEVELS for an UNKNOWN DURATION.\***

\* From: Chair Brad Miller, US House Subcommittee on Investigations and Oversight, 10/5/90 Letter to EPA Administrator Jackson

32

3.

Washington DC  
2001-2004:  
Lead-in-water crisis

33

**January 31, 2004**

**The Washington Post**

**Water in D.C. Exceeds EPA Lead Limit**  
Random Tests Last Summer Found High Levels in 4,000 Homes Throughout City

By David Nakamura  
Washington Post Staff Writer  
Saturday, January 31, 2004, Page A01

Tap water in thousands of District houses has recently tested above the federal limit for lead contamination, a new phenomenon that has baffled the D.C. Water and Sewer Authority and forced the agency to begin replacing service pipes.

Two-thirds of the 6,118 residences that WASA tested last summer, or 4,075 homes, had water that exceeded the lead limit of 15 parts per billion set by the Environmental Protection Agency in 1991. This is the first time the city's water has shown significant lead contamination since the late 1980s, officials said.

Image sources: <http://www.boston.com/News/Press.aspx>; <http://www.citizen.org/cnep/Water/us/other/dc/>

34

**Washington, DC 2003**

< LAL  
 > LAL

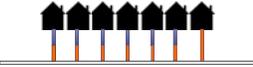
35

**Lead-in-water health guidance**

Organization	Lead (ppb)	Health Guidance
WHO*	10	Do Not Drink
CDC	15	Do Not Drink
EPA*	40	Imminent and Substantial Endangerment
EPA	5,000	Hazardous Waste

\* Also European Union (2013) and Canada  
# Posted on EPA website until March 2004

36



- Contamination followed November 2000 change in water treatment from **FREE CHLORINE to CHLORAMINE**
- DC WASA knew about lead-in-water contamination since 2001 => reported LAL exceedance to EPA Region 3 in 2002
- Began replacing LSLs in 2003: **of the 382 LSLRs that year, only 9 were FLSLRs**

37

- Late 2003:** Virginia Tech research: Began showing that **the chloramine in Washington DC's drinking water accelerated galvanic corrosion between lead and copper**
- 2/19/04:** Letter from Dr. Edwards to EPA: "...replacing a half a lead service with copper is going to dramatically worsen the galvanic corrosion between copper and lead. **Such partial replacements should be stopped immediately.**"

38

- 2/26/04:** "LEAD" coalition press conference

"Evidence is mounting that partial lead service line replacement often **will not solve the problem, and actually can make lead levels worse** by shaking loose lead in the pipes and causing galvanic corrosion that may exacerbate lead problems."



LEAD, 2004, Recommendations.

39



- 3/4/04:** Two homes tested **24,000 ppb and 48,000 ppb** after PLSLR

"Lead contamination of tap water in two District houses is **so extraordinarily high that experts say the residents might be able to taste it**, but city health officials never made more than routine efforts to inform the homeowners of the health risks."

Image sources: <http://1389blog.com/category/christianity/>

40

DC Department of Health (DOH) ordered DC WASA to **stop cutting LSLs** and **conduct additional testing** to determine the duration of lead spikes and identify safe construction practices.



Image source: [http://commons.wikimedia.org/wiki/File:Stop\\_sign\\_light\\_red.svg](http://commons.wikimedia.org/wiki/File:Stop_sign_light_red.svg)

41

- 3/17/04:** Letter to EPA from **Congressmen Tom Davis and Henry Waxman and Delegate Eleanor Holmes Norton**

Recent experience in the District indicates that replacing only the WASA-owned portion of a lead service line may actually increase lead levels at the tap. **EPA should research the effect of partial replacement of lead service lines and modify the regulations to address this issue.** If EPA confirms that partial replacement commonly causes a long term increase in lead levels or fails to produce any reduction in lead levels, it would make no sense to encourage such partial lead service line replacements.

42

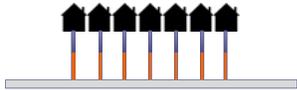
4.

2004 and 2006  
PLSLR studies

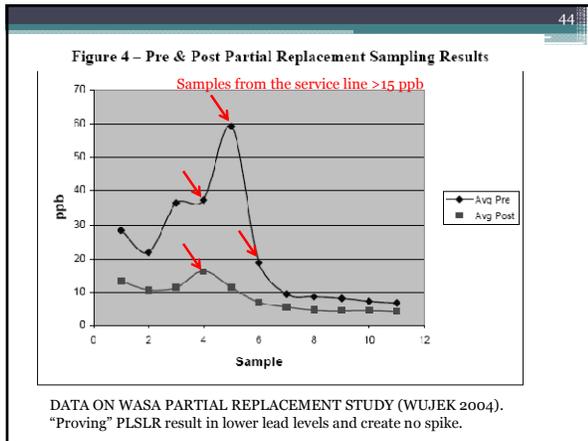
43

**2004 Wujek study**

- **DC WASA sponsored study in collaboration with EPA and DC DOH to “determine the duration of the temporary high lead levels”**
- **Goal:** to measure lead levels *before* PLSLR and for **2 weeks after** PLSLR
- **Scope:** 7 homes that underwent a 15-minute flushing of the tap *immediately* after PLSLR



Wujek, J. J., 2004, Minimizing Peak Lead Concentrations After Partial Lead Service Line Replacements [WJTC Conference Proceedings].



45

**Conclusion:**

- Flushing for 15 minutes *immediately* after PLSLR reduces lead spikes that can result from construction => **i.e., no problem with the physical disturbance of the lead pipe**
- The connection between new copper and old lead *does not* significantly increase lead in the water => **i.e., no problem with galvanic corrosion**

46

**5/4/04:**

**DC WASA request to DC DOH (cc-ed to EPA)**

“... see the attached initial sample results, together with a brief summary from John Wujek. **We would like to meet at your earliest convenience to discuss the results and obtain your approval to resume the replacement of services to the property line.**”

47

**DC DOH granted DC WASA permission to continue with PLSLRs**



Image source: <http://www.johnhanlin.com/>

48

**DC WASA:**

- o Launched a 1,734 PLSLR program for 2004
- o Signed an agreement with EPA Region 3 to partially replace ALL known LSLs (estimated at the time at 23,000) by 2010...

**...beginning the largest LSLR program in US history**

49

**4/4/05: EPA on NPR-affiliate radio show**

[...] WASA's data..., they did a very extensive short-term study last spring that looked at the effects of replacing lead service lines partially and found that **there was no immediate increase in lead levels in the tap water** as many had suspected or had been even seen in a few other very old research studies.

[...] **[Over the long-term] there is no evidence that the lead levels increase, in fact [...] you remove half the lead, you have a lot less lead in your tap water** as a result. It's not a perfect solution.

WAMU 88.5 FM  
AMERICAN UNIVERSITY RADIO

Image source: [http://baltimoreanimalshelter.org/images/barestoberfest/2009/sponsor\\_logos/wamu.png](http://baltimoreanimalshelter.org/images/barestoberfest/2009/sponsor_logos/wamu.png)

50

**What wasn't discussed**

**In the 2004 Wujek study:**

- Faucet **aerators were removed** prior to sampling (this can result in missing lead particles)
- After PLSLR, average lead levels in water that was in contact with the copper:lead service line remained **>15 ppb**
- The highest post-PLSLR sample (854 ppb) was **excluded from analysis** because it was assumed that it was not caused by the PLSLR

51

**What was later discovered via FOIA**

- Every water sample in the study was collected during a one month period (4/2/04-5/8/04) when DC's disinfectant was switched back to free chlorine (an effective corrosion control chemical)

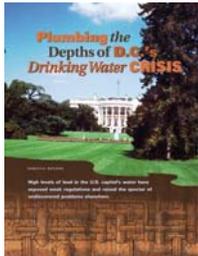
**NO CHLORAMINE IN THE WATER**

- Every water sample was collected with a **very low flow rate**, which can miss lead problems

52

**6/15/04: Environmental Science & Technology article**

- Discussed Virginia Tech findings about acceleration of galvanic corrosion between copper and lead in the presence of chloramine => **"Lead leaching can increase 4 to 100 times faster than normal"**



53

**7/9/04:**

- In response to the ES&T article, consultants for EPA Region 3 offered to conduct a study on galvanic corrosion

**"This could be especially important as WASA embarks on their aggressive program to replace all lead service lines (partial replacements mostly) in 6 years."**

- EPA Region 3 agreed to fund the research

Dufresne, e-mail to EPA R3 and Cadmus, obtained via FOIA

54

**2006 Reiber & Dufresne study**

- **Goal:** "...to determine if replacing a portion of a lead pipe with copper piping might cause accelerated lead release"
- **Method:** Controlled laboratory conditions designed to exacerbate lead release. Examination of connections between new copper and new lead vs. new copper and old lead.
- **Conclusion:** Galvanic corrosion is minimal and, in the long-term, likely inconsequential when LSL surfaces are well-aged and passivated, like in Washington DC.

Reiber & Dufresne, 2006, Effects of External Currents and Dissimilar Metal Contact on Corrosion from Lead Service Lines.

55

- 2006 Reiber/Dufresne study received as **proof that PLSLR in Washington, DC did not place residents at significant risk**
- Routinely distributed to DC residents and lawmakers at DC WASA meetings about lead
- Used on 4/15/08 by EPA Region 3 in Congressional testimony to allay concerns about PLSLR
- Still on EPA's website

56

**What wasn't made clear about the study:**

- Conclusions based on "surface potential" measurements, at best an indirect indicator of galvanic corrosion of lead
- At least some lead-in-water levels measured, but not reported in the paper and, to date, not released to the public even after multi-year FOIA requests
- Water not allowed to stagnate in the pipes, as occurs in practice and known to worsen galvanic corrosion problems

57

2007 FOIA revealed that **by 2006 DC WASA and EPA Region 3 had data showing lead spikes and ongoing lead problems in numerous homes with PLSLRs:**

**1st half of 2006**

Time after PLSLR	90 <sup>th</sup> percentile lead – 1 <sup>st</sup> draw	90 <sup>th</sup> percentile lead – 2 <sup>nd</sup> draw
0-1 week	140 ppb (25,800 ppb highest)	95 ppb (814 ppb highest)
1 week-1 month	22 ppb (17,400 ppb highest)	17 ppb (73 ppb highest)
1 month-596 days	17 ppb (47 ppb highest)	17 ppb (29 ppb highest)

58

- 2007 FOIA of Washington, DC environmental risk assessments at the homes of children with elevated blood lead levels revealed that **in 5 of 41 assessments parents reported having a PLSLR**




Images from: <http://www.dcaabhc.org/advocacy.html>; <http://www.examiner.com/de-in-washington-dc/now-hiring-district-department-of-the-environment-director>

59

**Washington DC: PLSLR program**

	2003	2004	2005	2006	2007	2008
<b>FLSLR*</b>	9	81	845	674	458	699
<b>PLSLR*</b>	373	1,734	3,239	3,338	3,362	2,404
<b>% of full</b>	2.4	4.6	26	20.1	13.6	29

**Total PLSLRs = 14,450 (81%)**  
**Total cost = >\$100 million in ratepayer money**

\* Data provided by DC Water, 6/4/10

60

**2008**

**DC WASA's accelerated LSLR program was terminated prematurely**

The decision was based in part on data obtained and exposed by the public showing that PLSLR sometimes resulted in lead-in-water elevations for months after replacement.



61

5.

CDC's 2010 announcement about analysis of Washington, DC data

62

**September 4, 2009: Letter to DC WASA**

Our results indicate that the risk of elevated blood lead levels  $\geq 10\mu\text{g}/\text{dL}$  in homes with partial replacement of lead service lines is about 4 times that of the risk for blood lead elevations in homes without lead service lines. We also noted an increase in risk for



63

**January 12, 2010:**

**CDC**  
**Online announcement to Childhood Lead Poisoning Prevention Programs across the US**

- PLSLRs are associated with **increased risk for elevated blood lead levels ( $\geq 10 \mu\text{g}/\text{dL}$ ).**



64

**The CDC states that it shared its findings with EPA in 2007**

10/5/10 letter from Congressman Brad Miller to EPA Administrator Lisa P. Jackson

65

**PLSLRs in the US**

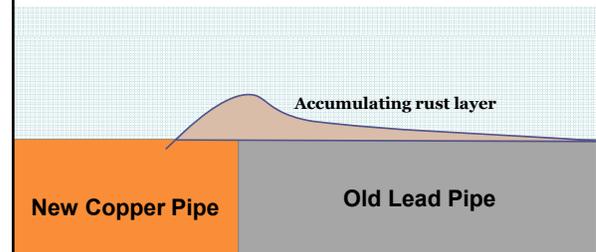
- LSLRs for LCR compliance have occurred in **at least 13 states, plus Washington, DC**
- This number **does not include "voluntary" replacements** that utilities conduct during distribution system maintenance, road repairs, and as a proactive measure to prevent lead-in-water contamination.

GAO, 2006, GAO-06-148

6.

Where is  
the science  
on PLSLR  
today?

**Real world observations:** Lead pipes excavated after 70-114 years in service showed that the rust layer that can form from galvanic corrosion **can contain hundreds of milligrams of lead per liter** (DeSantis et al. 2009)



#### Lab observations:

Increases in lead leaching after PLSLR

- Can be **short-term** (days to weeks) or **longer-term** (months to years) => **but there is a dearth of unambiguous data demonstrating the maximum duration, severity of this effect, and causes of worst-case leaching**
- Depend on the **water's chemistry** and on resident **water use patterns** (e.g., stagnation times, water flow)
- Can occur **whether the lead pipe is new or old**

(Triantafyllidou & Edwards 2010, submitted for publication)

7.

Social justice:  
policy  
and  
practice

#### EPA revisions to the LCR

##### Public stakeholder meeting 11/4/10

- EPA's presentation on LSLR made **no mention of "galvanic corrosion"** as a phenomenon of potential concern
- EPA **did not discuss** data or concerns about long-term lead-in-water problems after PLSLR
- All stakeholders present -- water utilities, lead corrosion scientists, health professionals, and lead poisoning prevention advocates -- called for a **MORATORIUM** on PLSLRs.

#### Questions

- **Unknowns remain** about:
  - Longer-term galvanic corrosion effects
  - Effective ways to protect consumers from excessively high lead spikes in the short- and long-term
- Who gets to define what constitutes **"acceptable risk"**?
- Is it accurate and ethical to present PLSLR as an effective **"remedial" action** in every case?

## Acknowledgments

- Marc Edwards and Simoni Triantafyllidou thank the **Water Research Foundation** for their financial support to study partial lead service line replacement.
- The presenters are in the process of receiving financial support from the **Robert Wood Johnson Foundation** for research on the Lead and Copper Rule.



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY  
NATIONAL RISK MANAGEMENT RESEARCH LABORATORY  
CINCINNATI, OH 45268

January 7, 1997

OFFICE OF  
RESEARCH AND DEVELOPMENT

MEMORANDUM

SUBJECT: More Thoughts on Partial Lead Service Line Replacement

FROM: Michael R. Schock<sup>MRS</sup>, Chemist  
Treatment Technology Evaluation Branch  
Water Supply and Water Resources Division

TO: Peter T. Lassoyszky, Environmental Engineer  
Targeting and Assistance Branch  
Standards and Risk Management Division, OGWDW (4603)

I agree with you that the AWWA information sent did not add anything useful to the debate. After thinking about it (for several years, plus the additional focus of the LCR revisions Work Group), I still have a problem with sticking with the original proposal. In fact, this is even a BURDEN INCREASE in several respects, as noted below.

EPA essentially admits--in the original reg--that higher "short term" lead levels are likely to result (FR p. 26505). However, almost no data is presented to show cases from different water qualities and treatments where lead levels above the action level are caused to go up some, then they go back down below the AL. The Scotland data (Britton and Richards) is inappropriate--Pb levels are much above the AL and they are much above still even after they go "down." The Oakwood data (I was involved in that study) was below AL for most sites, and the before and after cases were statistically insignificantly different. The Newport News study was ambiguous because the amount of service line replaced was not clearly documented. Replacing to the meter generally would mean complete replacement in many if not most areas of the country.

So, the bottom line is that EPA is promulgating a policy that KNOWINGLY INCREASES LEAD LEVELS for an UNKNOWN DURATION. This is at least inconsistent with the policy on public notification, where a delay requested by commentators of only a few weeks to allow synchronization of notice with billing cycles was considered to be unsupportable and potentially dangerous to pregnant women and young infants (for whom a few weeks or months would be a substantial part of the most vulnerable exposure period).

17

It is then proposed that residents be informed of the intent of the utility to replace the owned/controlled part of the service line, and that levels might rise. Even if water samples are taken and tested in accordance with §141.84(d), THERE IS NO REMEDIATION PROVISION. The utility is potentially forced to CAUSE a WORSE acute problem than originally existed, and the resident(s) are exposed to it for at least 14 days before a sample has to be collected, and an unspecified number of days before the lab results are back and they know the situation (as of the sampling date). Finally, what if the lead levels are still high? The residents are now forced to flush their lines repeatedly, buy bottled water or install some POU treatment device for an unknown period time. This is clearly an added expense and burden which is not addressed in the CFR language. In fact, the information about precautions at the top of the rightmost column on p. 26506 are not spelled out in §141.84(d).

In conclusion, I think that relying on the suppositions of the original preamble and "...EPA believes..." leaves EPA very vulnerable to a variety of charges about potentially aggravating a bad condition, increasing the economic burden to residents (often poor ones), and not having defeasible data upon which to base the suppositions. I hope the suppositions are right.

cc: Robert M. Clark  
Judith M. Lebowich (4603)  
Jeffrey B. Kempic (4603)  
Robert C. Thurnau  
James J. Westrick



*Excerpt Congressional  
Testimony*

**The Charles Edward Via, Jr. Department of  
Civil and Environmental Engineering**

VIRGINIA POLYTECHNIC INSTITUTE  
AND STATE UNIVERSITY

418 New Engineering Building, Mail Code 0246  
Blacksburg, Virginia 24061  
Phone: (540) 231-6131 Fax: (540) 231-7916

Chairman Tom Davis and the Committee on Government Reform  
U.S. House of Representatives  
2157 Rayburn House Office Building  
Washington, D.C. 20515

March 2, 2004

Re: Written Testimony March 5, 2004

I am a Professor of Civil Engineering at Virginia Tech and have devoted much of my career to lead and copper corrosion issues for which I am internationally recognized. I was awarded a Presidential Faculty Fellowship by the White House and the National Science Foundation in 1996 for this work. I am the current President of the Association of Environmental Engineering and Science Professors. Over the last four years, I have worked intensively on corrosion issues experienced by consumers and utilities using Potomac River water. These efforts include research work with the Washington Suburban Sanitation Commission (WSSC) on copper pitting and Fairfax, VA on a desk top study to pre-empt possible problems with lead leaching in drinking water. My research team at Virginia Tech has conducted hundreds of corrosion experiments using real or simulated versions of Potomac River water.

More specific to the current issue in question, I worked for Cadmus as sub-contractor to the United States Environmental Protection Agency (US EPA) in efforts to understand the problem of excessive lead in the drinking water of the District of Columbia Water and Sewer Authority (DC WASA) customers. I have personally collected water samples in the homes of DC WASA customers in an attempt to understand the problem of copper pitting in their homes, and in the process, I discovered a very serious problem with lead contamination that is the focus of today's discussion. I designed the sampling plan DC WASA executed through mid-December 2003, which first unambiguously illustrated the very serious nature of the existing lead problem to both DC WASA and EPA. I also designed many of the experiments that are now in progress at DC WASA to improve understanding of the problem, and I recommended mitigation strategies that they could employ to mitigate the problem. Indeed, to my knowledge, I was the only expert who gave significant advice to the US EPA and WASA on the lead problem through at least mid-December of 2004.

I have very strong concerns regarding the way in which the US EPA has handled the present crisis. I have expressed most of these concerns directly to the US EPA in detailed letters I sent to George Rizzo and Cynthia Dougherty on February 8<sup>th</sup> and February 10<sup>th</sup>. I am willing to share these letters with anyone interested in learning the full extent of my concerns or developing a detailed timeline of events. In this letter I will focus on two opinions that I have developed. The first is that US EPA actions are not adequately protecting consumers' from excessive levels of

19

I point out that EPA is not even sure of the simplest things, such as the whether the required partial replacement of lead service laterals is actually beneficial or not. According to our experimental results in November 2003, the lead in water at DC WASA is being driven by a galvanic (battery) reaction between copper:lead or copper:brass. Replacing old lead with fresh copper, and connecting the fresh copper to the consumers lead pipe, would therefore be expected to make lead release much worse that it was before. Personally, I am appalled that we do not even know if the expensive partial lead service line replacement program is beneficial. In simple terms, DC WASA might very well spend \$351 million to finish the job of partial lead service line replacement, leaving behind a much worse problem for consumers that if they had done nothing at all. In my letter on this subject written February 19<sup>th</sup> to the new expert team that is starting at DC WASA, I stated the following about our results at Virginia Tech:

*"We have proven ..that not only does chloramine worsen galvanic corrosion between brass/copper or lead/copper, but it also increases the amount of lead leached to the water when the metals are coupled. Our findings...raise a host of problems as I mentioned yesterday. Specifically, replacing a half a lead service with copper is going to dramatically worsen the galvanic corrosion between copper and lead. Such partial replacements should be stopped immediately....."*

I will point out that a term has even been coined to explain the finding that lead in drinking water is often much higher after meeting the letter of the law and replacing part of the service lateral. It is called "the partial replacement phenomena." Incredibly, because the law says to replace lead services, they will continue to do so even though their own data often shows they are making the problem worse. Some of the lead levels reported to me (second hand) in homes after such partial replacements are truly stunning, and are as high as 48,000 ppb if my source is accurate. Does the law require that we suspend common sense?

Let us be honest about what is happening here. We are learning hard lessons about corrosion control in full scale testing of real systems, while consumers are drinking the water and getting continual reassurance that everything is under control. In my opinion the situation is not under control by any rational measure.



**The foregoing disclosure was acknowledged before me on March 8, 2004.**

---

Michael R. Schock  
Chemist  
Treatment Technology Evaluation Branch  
Water Supply & Water Resources Division, MS B-24  
National Risk Management Research Laboratory, USEPA  
26 W. Martin Luther King Dr.  
Cincinnati, OH 45220-2242  
513.569.7412 (P) 513.569.7172 (fax)

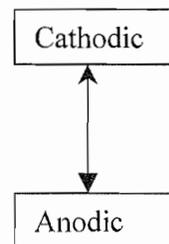
March 6, 2004

Dear Mike,

We have made some additional substantial experimental progress on the issues I raised in my letter February 19<sup>th</sup>, 2004. I am now bringing that progress to the attention of the expert team so that you can, hopefully, more strongly endorse my recommendation to immediately stop the partial lead service line replacements. As you know, this is a practice that is being required to reduce consumer exposure to lead. Since last December I have been very concerned that this practice might be making the situation much worse rather than better.

In addition to the practical data that I sent you back on the 19<sup>th</sup> proving my concern in concept, I thought it would be helpful to present additional information that shows why the partial service line replacement program is predicted to make things worse. I also add an important new concept that we have developed and tested since my last letter. Every freshman chemistry student is familiar with the galvanic series, which for metals used in drinking water is as follows:

- 1) Copper
- 2) Brass (with lead)
- 3) Lead
- 4) Iron
- 5) Galvanized
- 6) Magnesium



The galvanic series is useful in predicting many corrosion phenomena. As per my presentation January 22, 2003 in South Carolina, if zinc is connected to copper, a battery is formed because the copper is cathodic to zinc (Figure 1).<sup>1</sup> The copper is protected from corrosion whereas the zinc is eaten away and forced to corrode at a high rate. As the zinc corrodes, the zinc leaches into and contaminates the water. This concept is commonly applied to protect water heaters (Figure 2).

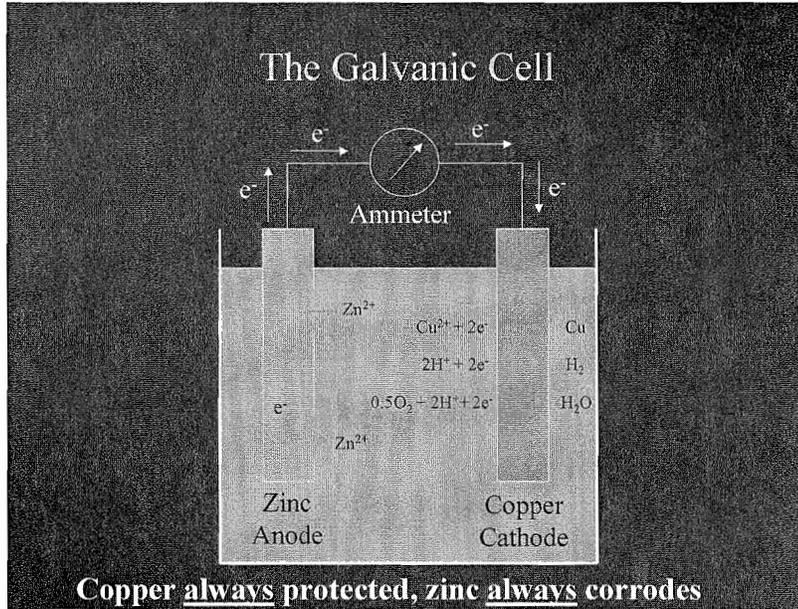


Figure 1. Formation of a battery when two dissimilar metals are connected.

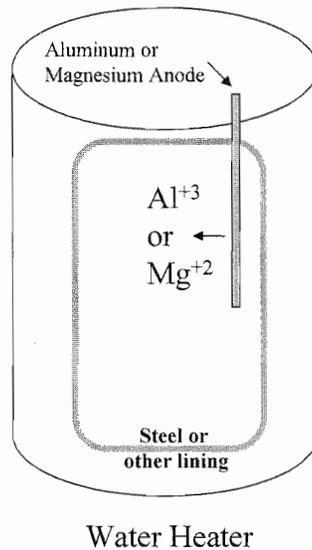


Figure 2. Connection of aluminum or magnesium anode to steel lining inside a water heater creates a battery, protecting the metallic lining, but accelerating corrosion of the aluminum and magnesium anode. The  $Mg^{+2}$  and  $Al^{+3}$  are released to the water. The anode is said to be sacrificed.

Because brass and lead are both anodic to copper, connecting brass directly to copper can be problematic (Figure 3). Specifically, corrosion of the brass or lead is accelerated, which in turn, can dramatically increase the amount of lead leached to the water. Corrosion engineers also understand that the cathodic reaction (which is occurring at the copper pipe surface) is often rate limiting. Thus, to the extent that the reaction occurring at the copper surface is accelerated, the lead problem will be worsened, *even if you decrease the amount of lead surface that is present as occurs during a partial service line replacement*. This is an important concept that you and the other experts understand, but that a normal water treatment person or regulator has difficulties with.

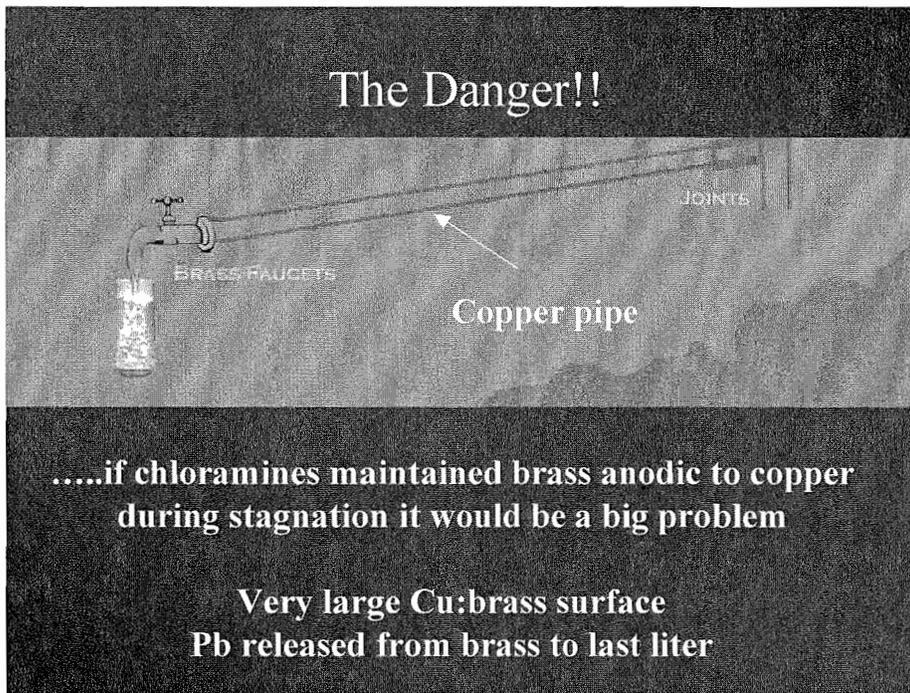


Figure 3. Lead problem that arises from hooking brass or lead to copper.

In a water heater, as the steel lining passivates with age, the battery effect decreases markedly. Consequently, the rate at which the anode is sacrificed and the  $Mg^{+2}$  or  $Al^{+3}$  leach to the water also decreases. If the old anode is removed and connected to a new water heater with fresh exposed steel, the rate at which the old  $Mg^{+2}$  or  $Al^{+3}$  anode is sacrificed will increase. In the current situation, this is very important. Specifically, in response to my input in the letter of February 19<sup>th</sup>, 2003, some experts might assert that “the lead at WASA has been hooked directly to copper pipe for years, and therefore the partial service line replacement is not introducing a new condition that is significantly worse.” That statement is false. Connection of brand new copper to old lead will provide fresh cathodic surface that will accelerate corrosion of old lead and brass. This is due to both 1) the increased cathodic surface area, and 2) the “newness” of the copper surface.

I also point out the importance of pipe sequencing as an even more important factor. Specifically, it is well understood that problems with galvanic corrosion are lessened if the following sequence of connections is followed for water pipe (see Appendix 1):

Galvanized steel to iron to lead to copper

In addition to the fact that such connections minimize the strength of the battery effect between dissimilar metals, over the years we have learned that the above principle is even more important for another reason. Specifically, we want to avoid the dangerous problem of deposition corrosion.

Deposition corrosion can occur when ions of a more noble metal are present in the water that flows into the more anodic metal. In the present instance, deposition corrosion proceeds through the following sequence of steps (Figure 4):

- 1) copper ions released at the fresh copper surface
- 2) copper deposits and is plated onto the old lead
- 3) the new copper coating on the lead accelerates corrosion dramatically
- 4) more lead is released to the drinking water

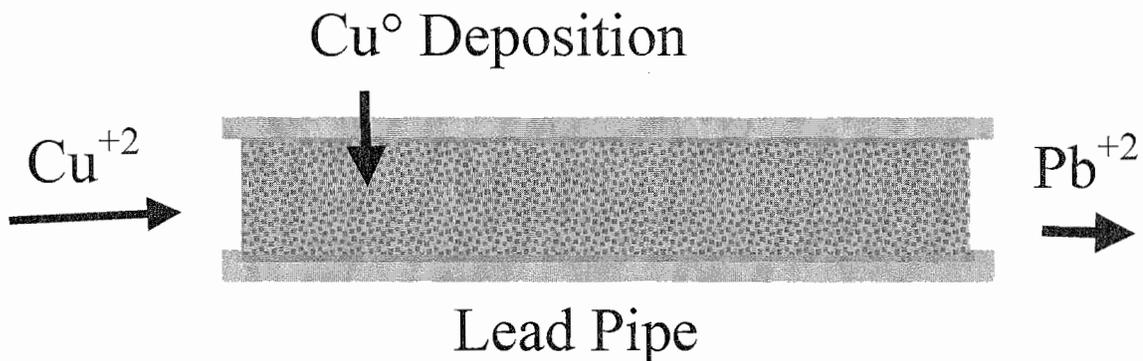


Figure 4. Placement of copper pipe upstream of lead can cause a serious long term lead problem through deposition corrosion.

In other words, it is not just the fact that new copper is directly connected to lead that is the only problem. It is also the fact that if new copper is placed before the lead, cupric ions can deposit on the old lead pipe. It does not matter if the copper came from water meters or from the new copper service lateral, this deposition is expected to dramatically accelerate lead corrosion rates.

This concept is well established scientifically. For instance, the following quote is taken from CORROSION BASICS: An Introduction, edited by L.S. Van Delinder, NACE, Houston, Texas, 1984:

*“Deposition corrosion is a form of pitting corrosion that can occur in a liquid environment when a more cathodic metal is plated out of solution onto a metal surface. It generally occurs with the more anodic metals such as magnesium, zinc, and aluminum. Common cathodic*

5/24

*"activators" are mercury and copper ions in solution. For example, soft water passing through a copper water pipe will accumulate some copper ions. If water is then admitted to a galvanized or aluminum vessel, particles of metallic copper will plate out, i.e., deposit on the surface and stimulate pitting by local cell action. Deposition corrosion can be avoided by preventing the pick-up of cathodic ions that will enter the equipment...."*

When lead anodes are used to plate copper, it is found that copper contaminants "caused increased lead corrosion, due to the fact that lead dissolution can also couple spontaneously with copper deposition on the lead surface" (Cifuentes, 2001).<sup>2</sup>

The water industry also has experiences with deposition corrosion. Specifically, while I am not aware of previous research examining the direct effect of cupric ion on lead corrosion rates (other than those we are conducting at Virginia Tech), the fact that dissolved copper accelerates corrosion of iron pipe is well understood. Specifically, it has been reported that dissolved copper concentrations as low as 0.01 mg/L can dramatically increase iron corrosion rates in drinking water.<sup>3,4,5</sup>

For further information, see page 8 of Appendix 2 for additional discussion of deposition corrosion. Also, note the explicit recommendation in Appendix 1, which states "A lead service requiring repair would be best removed and replaced completely with copper."

My final point in this development is that we have shown that the chemical conditions present at DC WASA including 1) relatively high oxidant residuals, 2) higher pH and 3) significant aluminum in the water can elevate the potential of copper by several hundred millivolts relative to the typical situation.<sup>6-10</sup> Consequently, any copper surface in the system, whether it is plated on lead or is pure copper pipe, is going to be a much stronger cathode than normal. In other words, all of the problems noted above for a "normal" copper:lead connection will be magnified.

Apparently due to the legal advice of DC WASA and perhaps even the US EPA, my communication with the expert team seems destined to be virtually all one way. I am not aware of what the expert team is doing, saying or recommending. Consequently, misunderstandings are possibly arising on my part regarding the advice that you are giving to the US EPA or DC WASA. As you know, I am on the record criticizing the actions of the US EPA and DC WASA in handling this incident. I personally think that this is going to be remembered as one of the biggest public health fiasco's in recent memory. In my opinion, the new expert team has a critical role to play in helping to stop the damages that are still occurring to consumers as we speak.

Therefore, I am asking you to discuss, and to advise, the US EPA and DC WASA on two very important issues that deserve immediate attention. First, since last October, I have been warning the US EPA and WASA that they should not assume the problem with lead is limited to old homes with lead service lines. My sampling plan that DC WASA started to follow in November was supposed to have also sampled new homes. My own data, collected from buildings in March 2003, showed that there was once a very serious problem with lead in apartment buildings. I have been told those apartments did not have a lead service line. The recent

Arlington data also is directly supportive of my concern that the problem is not limited to old homes with lead service lines.

In the paper recently, DC WASA was quoted:

*"My understanding, from what I've heard from the experts upon whom we rely, is that they're focusing on homes with lead services lines," Gerstell said at a news conference.*

Obviously, I am not an expert upon whom DC WASA and the EPA rely, since I warned them of a problem with new homes and lead from brass back in October. That warning was backed up with my own field sampling data. Do you now have data that shows this problem is limited to homes with lead service lines?

I also sent a letter to the expert team on February 19<sup>th</sup>, with some strong language regarding the partial lead service lead replacement program. That program has not been stopped, but rather, it has been accelerated. We are informed of samples, collected from homes after partial service line replacements "fixed" the problem, that show lead levels as high as 48,000 ppb (more than 3200 times the EPA action level) in flushed samples. I am sending this letter, today, to re-iterate my concerns about this program. Specifically, I am asking whether DC WASA or the US EPA have actual data proving that the partial lead service replacement program is not causing a serious problem? If you do not have such data, is it not wise to recommend discontinuing the partial service line replacement program in the strongest possible terms, especially given the fact that it is predicted to cause a serious long term problem with lead? Forgive me if you have already backed up my recommendation to stop this program, and DC WASA and EPA have refused to comply, or if you have data in hand proving that the program is not causing a problem. I am very hopeful that the US EPA and DC WASA will henceforth only make complete lead service line replacements.

Regards,

Marc Edwards  
Professor of Civil and Environmental Engineering  
Virginia Tech

Attachment #1  
Attachment #2

1/24

## References

1. Edwards, M. You and your plumbing. What you do not know can hurt. Presented to the South Carolina AWWA. Greenville, SC. January, 2004.
2. Cifuentes, L. The Corrosion Behavior of Lead Anodes in CuSO<sub>4</sub>-H<sub>2</sub>SO<sub>4</sub> Electrolytes. Presented at the 2001 Joint International Meeting - the 200th Meeting of The Electrochemical Society, Inc. and the 52nd Annual Meeting of the International Society of Electrochemistry - San Francisco, California.
3. Hatch, G.B. Control of Couples Developed in Water Systems. *Corrosion*, 11:1:15 (1955).
4. Cruse, H. Dissolved-Copper Effect on Iron Pipe. *Jour. AWWA*, 63:2:79 (1971).
5. McNeill, L.S., and M. Edwards. Iron Pipe Corrosion in Distribution Systems. *Journal American Water Works Association*. V. 93, No. 7, 88-100 (2001).
6. Marshall, B.J., Rushing, J.C., and M. Edwards. Confirming the Role of Aluminum Solids in Copper Pitting Corrosion. Proceedings of the American Water Works Association National Conference in Anaheim, CA. June, 2003. T-7-2. 13 pages.
7. Edwards, M. Initiation and Propagation of Localized Corrosion in Water Distribution Systems. Invited Lecture at the 2002 Gordon Conference on Aqueous Corrosion. Colby-Sawyer College. July, 2002.
8. Edwards, M., J.C. Rushing, S. Kvech and S. Reiber. Assessing Copper Pinhole Leaks in Residential Plumbing. In "Scaling and Corrosion In Water and Wastewater Systems." Edited by Simon Parsons, Richard Stuetz, Bruce Jefferson and Marc Edwards. *Water Science and Technology* p. 83-90 V. 49, N. 2 (2004).
9. Rushing, J.C., and M. Edwards. Role of Chlorine and Aluminum in Pitting Corrosion of Copper Pipes. Proceedings of the 2002 Water Quality Technology Conference in Seattle Washington. November, 2002. W-5 15 pages.
10. Edwards, M. Degradation of Drinking Water Treatment Plant Infrastructure by Enhanced Coagulation. Presented October, 2003 at the AWWA Distribution System Conference. Portland, OR.

SUPPLEMENTARY INFORMATION TO TESTIMONY OF  
JON M. CAPACASA  
DIRECTOR, WATER PROTECTION DIVISION  
ENVIRONMENTAL PROTECTION AGENCY, REGION 3  
BEFORE THE  
FEDERAL WORKFORCE,  
POSTAL SERVICE AND THE DISTRICT OF COLUMBIA  
SUBCOMMITTEE OF THE  
HOUSE OVERSIGHT AND GOVERNMENT REFORM COMMITTEE  
April 15, 2008

1) *EPA report on effects of galvanic and grounding currents on corrosion ("Effects of External Currents and Dissimilar Metal Contact on Corrosion from Lead Service Lines")*

As referenced in testimony presented on April 15, 2008, the report of a study performed on behalf of EPA Region 3 is available at:

[http://www.epa.gov/dclead/grounding\\_effects\\_study\\_final\\_november\\_2006.pdf](http://www.epa.gov/dclead/grounding_effects_study_final_november_2006.pdf)

Please note that in March 2008, EPA Region 3 learned that a statement made on page 15 of this report regarding DCWASA's use of dielectric couplers during partial lead service line replacement (PLSLR) is incorrect. DCWASA does not use dielectric couplers when performing a PLSLR. This clarification is posted on EPA's website at (its about 1/3 down the page under the Galvanic Corrosion section, right below the link to the galvanic corrosion report):

<http://www.epa.gov/dclead/corrosion.htm#research>

5/29/2008

Re: The US EPA Region III Study on Partial Replacements and Galvanic Effects  
To: Joseph Cotruvo, DC WASA Board

I am very familiar with the history, planning, and execution of the United States Environmental Protection Agency (U.S. EPA) Region III study that is now being touted as proof that partial replacements in Washington D.C. cannot cause a long term problem of consequence, and that galvanic effects between coupled lead and copper are "inconsequential" relative to lead leaching to water. I strongly believe that this study is a third rate scientific hack-job. It should be an embarrassment to the U.S. EPA

My abbreviated logic is presented in two sections providing evidence that:

- 1) The study relied on false assumptions and information which tainted its conclusions.
- 2) All lead in water data collected during the study, at least some of which contradicts the study's key conclusions, have been covered up. The data that are presented do not support the study's conclusions.

I base this analysis on information I obtained through Freedom of Information Act (FOIA) requests and other documents. Some of these materials are in the PDF attachment in the e-mail accompanying this letter.

### **1) The study relied on false assumptions and information**

The initial proposal for the study, the Quality Assurance Plan (QAPP), the preliminary report and final report present numerous items as facts which are now known to be highly misleading or false.

1.a. Before the study was conducted and even before the first data point was collected, it was clearly believed that DC WASA already had proven that the partial replacement program reduced lead in water and did not make lead leaching worse. It was also stated that DC WASA had practical data showing there was no effect. As evidence for this, the following excerpts of relevant documents obtained via FOIA are presented.

**Although DC WASA has developed substantial evidence that Partial Lead Service Line Replacement (PLSLR ) does not exacerbate lead release rates, and can in fact substantially reduce overall drinking water lead concentrations in the home; there is still a Study proposal, Attachment 1, page 20, July 12 2004**

40

## INTRODUCTION

The recent DC WASA experience relative to LSL replacement indicates that PLSLR does not exacerbate lead-release rates, and can in fact reduce overall drinking water lead concentrations in the home. While this evidence appears strong, there remains a debate

White paper, Attachment 1, page 14, September 28 2004

Galvanic corrosion has been well documented and occurs when two dissimilar metals are joined together. Theoretically joining lead and copper pipes together creates an electromotive difference in the 50 to 100 mV range, which should certainly accelerate corrosion. Practically, however, this effect has not been observed in the WASA service lines. This may be because of the relatively

QAPP Attachment 1, page 31 June 13<sup>th</sup> 2005

meaningfully increase LSL corrosion rates. Moreover, partial LSL replacement in the DCWASA system has not resulted in observed increases in lead release. (J. Wujek, *Minimizing Peak Lead Concentrations After Partial Lead Service Line Replacement*, WQTC, San Antonio, 2004)

Draft report, Attachment 1, page 28, July 23 2005

increase LSL corrosion rates. Moreover, partial LSL replacement in the DCWASA system has not resulted in observed increases in lead release (Wujek, 2004). In fact, the recent DC WASA experience relative to LSL replacement suggests that in the long term PLSLR does not exacerbate lead release rates, but rather reduces overall household drinking water lead concentrations in proportion to the amount of LSL replaced. While

Final Report, November 2006

The truth is that when DC WASA was asked to present any data that PLSLR reduced overall lead in water (or refute the idea that lead in water spiked) in early 2008, they could not do so. DC WASA's prior misleading statements and research therefore permeated the planning and interpretation of the entire US EPA study, to the point that the QAPP states that the key hypothesis supposedly being tested had already "practically".."not been observed" in the DC WASA system.

As for the 2004 Wujek study that Dr. Reiber cites for his "proof" that no spike occurs, and that only benefits from PLSLR are observed in D.C., the record shows that this study was conducted during the time period when free chlorine was present in DC WASA water. Every datapoint of the study is therefore meaningless relative to determining whether spikes occur, or whether there are long term benefits of PLSLR in the DC WASA system. This is why the Wujek study is no longer being cited by DC WASA and US EPA as evidence of anything at all. In a phone conversation I had with Dr. Reiber in late 2007, I was shocked to learn that he was completely unaware that every point of the Wujek study had been collected when chloramine was absent from the water.

1.b. DC WASA provided false information that fed into assumptions and interpretations made for the US EPA Region III study. Specifically:

***Dielectric Insertion.***

A dielectric is an insulating device that prevents direct electrical contact between dissimilar metals, and hence avoids at least some of the problems associated with galvanic coupling. Although not always used, it is generally considered good plumbing practice to use a dielectric when different metal plumbing materials are to be connected. It is standard policy for DC WASA to use dielectric couplers when performing partial LSL replacements (DC WASA, 2004).

Figure 11 shows the effect of inserting a dielectric coupler between the passivated LSL and copper sections of the directly coupled test rig. While in the previous water quality testing it was shown that the galvanic effect of the direct coupling was largely limited to the copper line and had little effect on the LSL, the insertion of a dielectric removes any galvanic impact from either surface. This is a particularly important finding, and along with the general polarization resistance of passivated LSL sections, explains why the partial LSL replacement program in the DC WASA system has not exacerbated lead conditions, but rather has helped to reduce household lead levels.

Final Report, page 15, November 2006

DC WASA has now admitted that it never installed a dielectric. Their false statement created a “safety net” specifically cited by the author. That is, even if galvanic effects were important to lead leaching, because it was understood that DC WASA always installed a dielectric it could not be important in D.C..

The above also clearly reinforces the authors’ misconception that DC WASA had data showing “the partial LSL replacement program in the DC WASA system has not exacerbated lead conditions, but rather has helped to reduce household lead levels.” DC WASA does not now have, nor has it ever had, data which proves anything of the sort.

- 2) All lead in water data collected during the study, at least some of which contradicts key conclusions, were “buried.” The data that are presented do not support the study’s conclusions.

The only data that can be used to “prove” that galvanic connections between lead and copper do not increase lead in water, are those measurements collected during the study of actual lead in water. Documents produced via FOIA demonstrate that this data was critical to the study design and to allow conclusions to be drawn as is intuitively obvious. Extensive planning and taxpayer funds went into the collection of the lead in water data during the study.

A preliminary report obtained via FOIA indicates that at least some lead in water data was collected. For example, one conclusion stated that:

**Metal Release.** Metal release from unpassivated LSL sections (scale removed) is exceptionally high when galvanically coupled. Metal release from passivated LSL

Attachment 1, page 29 July 23, 3005

The conclusion that the galvanic connection between lead and copper could cause "exceptionally high" lead release (to water) in at least some circumstances was inexplicably deleted from the final report. This is not a trivial omission. For example, as the authors clearly note, the lead pipe in the D.C. system was unpassivated whenever chloramine was in the water:

In the DC WASA case, however, the passivating corrosion scales formed on the LSLs in the presence of chloramines are clearly less protective than those formed in the presence

Attachment 1, page 15, September 28 2004

Knowing of the critical importance of this lead in water data, I repeatedly tried to get the actual lead in water data that was collected during the study throughout 2007 by FOIA of EPA. According to the QAPP (see for example page 35 of attachment 1) lead in water measurements had to be collected "several times a day." US EPA Region III either cannot, or will not, produce this important data to me. Perhaps the DC WASA board would have better luck in trying to obtain the actual lead in water data collected during this study, and see for themselves whether high levels of lead were detected.

When asked about this issue, of drawing conclusions about lead in water without presenting any lead in water data, the authors claimed that:

The short term tests used in this study did not readily lend themselves to standard metal release monitoring used in other aspects of the DC WASA corrosion control optimization studies. While monitoring metals release rates was attempted, it was found that the physical cutting and manipulation of LSL

sections generated frequent and irregular particulate release. The individual tests, which generally ran for periods of only a few days each, did not provide sufficient time to condition and stabilize the scales on the different test sections.

Page 12 and 13 of Attachment 1.

Frankly, this is a pathetic excuse. The cutting and manipulation during the study are not any more severe than the digging, cutting and manipulation that occur during an actual partial replacement. The fact that "frequent and irregular particulate release" was observed in the experiment is exactly the type of problem that we are concerned about relative to PLSLR in the DC WASA system. Rather than exclude this important data and information from the final report, the authors should have discussed the problem openly relative to potentially harmful lead exposure at the tap. The report authors had every opportunity to run this experiment for months, if necessary, to see what occurred relative to actual lead in water with time and to obtain meaningful conclusions.

If the key data for the study could not be collected, then no definitive conclusions should have been drawn at all. Moreover, caveats, such as that indicating that metals release can be exceptionally high from galvanic connections in some cases, should have been included in the final report. It is my personal suspicion that the actual lead in water measurements were "buried" because they were very high, and therefore, were illustrating a serious problem that is perfectly representative of what actually does occur in the DC WASA system. However, because the results directly contradicted DC WASA's purported experiences (which we now know do not exist and never did) the data was deemed "wrong" and hidden.

I would like to point out that it was well-understood before the US EPA Region III report that galvanic effects can sometimes have very serious impacts on lead in water leaching. For example, I am attaching a peer reviewed journal paper by Britton that cites work in Scotland, demonstrating much worse lead leaching in situations when lead pipe is connected to copper (see relevant excerpt in appendix 1 of this letter). ***In addition, it notes that putting a copper pipe in front of lead pipe (as DC WASA has done) can be especially serious due to a phenomenon known as "deposition corrosion."*** Similar references to problems resulting from lead pipe and copper pipe connections also appear in the standard reference book in our field (Internal Corrosion of Water Distribution Systems, 2nd Edition AWWARF). Indeed, we routinely see serious problems in the laboratory whenever we connect lead to copper pipe (using actual measurements of lead in water). I even presented data on this in March 2004 to the DC Council when I warned them of problems with partial replacements (see slides 1 and 2 in appendix 2 of this letter).

To illustrate a few final points, before the final report was written I discovered that the researchers did not even use Washington D.C. water in their testing. Instead, Seattle water was used. This makes the results completely worthless relevant to the situation in Washington D.C.. The researchers also conducted the entire study with continually flowing water, instead of imposing stagnation as frequently occurs in home plumbing. It is well-known that the worst lead in water problems are produced as a result of galvanic connections during stagnation.

I note that it is hypothetically possible that the galvanic connections between the copper and lead (with no dielectric present) may currently be increasing actual lead in water insignificantly in Washington DC. It is also possible, even likely, that the connection has created a problem with "frequent and irregular lead release" of "exceptionally high" concentration lead. The report that DC WASA and US EPA Region III have cited and distributed is completely worthless in clarifying the situation beyond these two hypothetical extremes. The fact that this "study" is even being mentioned in public by the two agencies, with all the obvious misrepresentations and false assumptions it contains, is extremely worrisome. Indeed, the entire incident is a perfect example of why these two agencies have no credibility on the issue of lead in Washington D.C. water.

Please call me at (540) 231-7236 if you should have any questions about this letter, my experiences related to this study, or my expertise about the role of galvanic corrosion in contributing to lead in water problems.

Regards,

Marc Edwards  
Charles Lunsford Professor of Civil Engineering

## MIXED METAL PLUMBING

Studies in Glasgow<sup>8</sup> have indicated that galvanic corrosion of lead caused by dissimilar metals in the pipework could exacerbate plumbosolvency. Frequently during the repair of a lead pipe a section of copper pipe would be inserted, and this section could then raise the water lead concentration in two ways; by direct electrochemical corrosion of the adjacent surfaces of copper and lead, and by the take-up and deposition of copper on to the lead pipe as the water passes in turn through each pipe section. Each site of copper deposition has potential to act as an individual galvanic cell, depending on the nature of the lead pipe surface and the corrosion products present. Table IV shows results taken from a detailed study of 195 households in Glasgow<sup>9</sup> of which 186 had all or some lead services. It was found that 69 households had some pipe sequence including at least one copper/lead/tap sequence and of these 43 yielded samples with abnormally erratic or much higher than normal lead concentrations. Thus only 38% of such properties gave satisfactory samples whereas for all other properties 89% gave satisfactory samples. Occasionally the insertion of copper pipe can produce particularly bad results and despite satisfactory pH control it may be impossible to obtain any satisfactory samples. This situation is exemplified in Fig. 5.

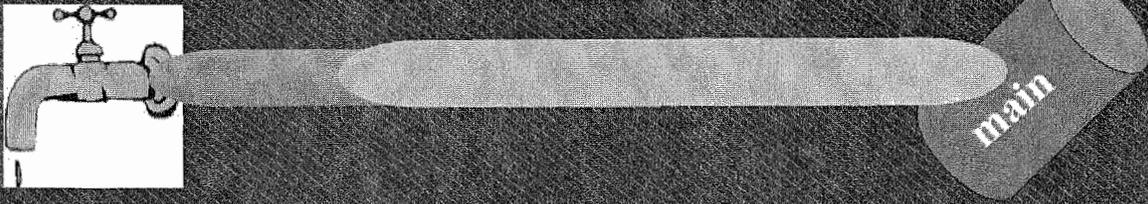
Of the 186 properties with lead services 155 had copper pipe abutting the tap and for 111 of these the length of 13mm copper pipe involved was less than 8m (one litre capacity). Thus the one litre first draw sample or random day time sample would include water from around the lead/copper junction. In many cases electrochemical action at this junction appears to increase lead concentration. This may help explain unexpectedly high lead concentrations in some first draw samples and may contribute to the rapid increase in water lead concentrations for the properties shown in Fig. 1. Further evidence of this effect for one of these properties is shown in Figs. 6 and 7 where the contribution to the water lead concentration from the area around the lead/copper junction is obvious. These electro-

TABLE IV. PLUMBOSOLVENCY STUDY OF 195 HOUSEHOLDS IN GLASGOW

Details	Households studied		Households giving satisfactory samples	
	Number	%	Number	%
Total number of properties	195	100	138	71
with copper plumbing systems	9	5	9	100
with lead lined tanks	26	14	0	0
with systems incorporating a copper/lead junction	69	35	26	38
with systems terminating in copper at tap:				
with lead prior to terminal section of copper	89	46	76	85
with lead and/or copper/lead prior to terminal section of copper	155	79	92	59

45

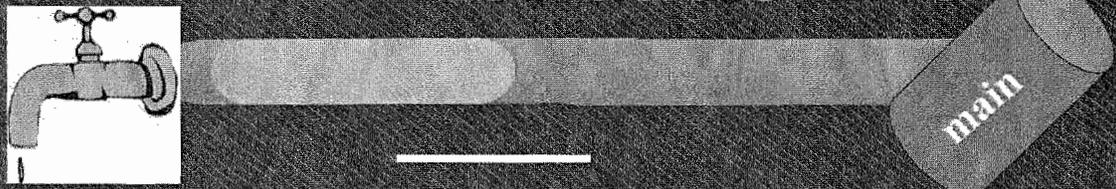
# Old Situation



Iron is sacrificed,  
Pb and Cu protected

The diagram shows a faucet on the left connected to a horizontal pipe. The pipe is labeled 'main' at its right end. The pipe is shaded to indicate its length and position.

# New Situation

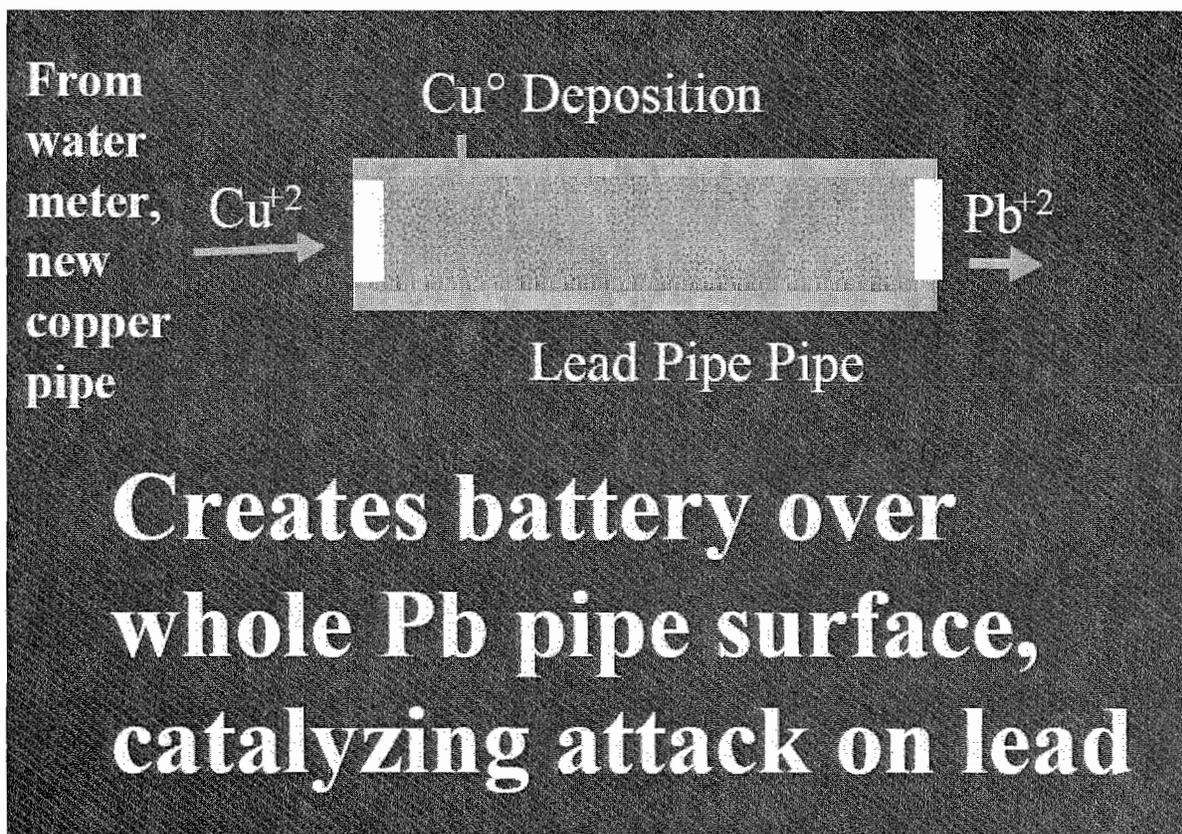
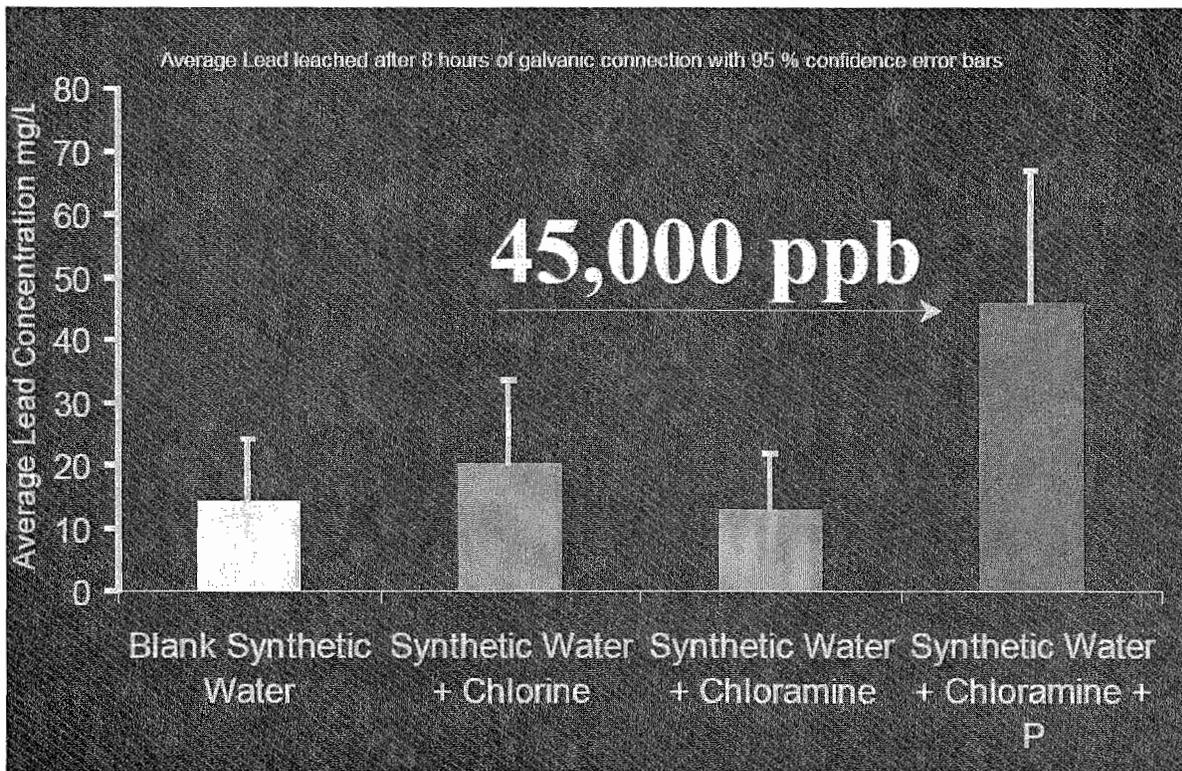


0.5 V battery

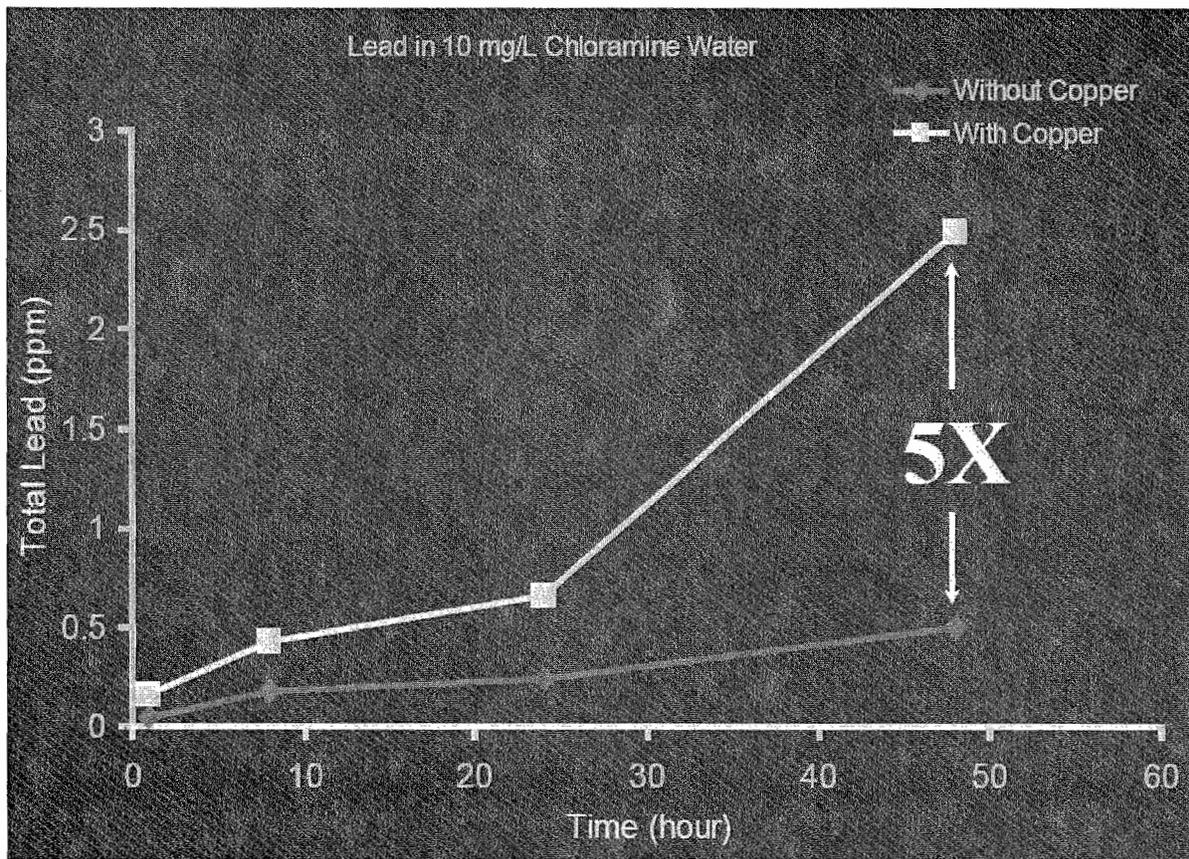
Pb is “sacrificed”

Even 1 foot of lead pipe contains enough lead to contaminate every drop of water a family will use in 100 years....it is not just the amount of lead, but the rate of corrosion

The diagram shows a faucet on the left connected to a horizontal pipe. The pipe is labeled 'main' at its right end. A 0.5 V battery is connected to the pipe, with a horizontal line representing the battery's terminals. The pipe is shaded to indicate its length and position.



47



Deposition corrosion effect presented to the D.C. Council in 2004. Because of deposition corrosion, installing a copper pipe in front of a lead pipe can generate serious long term consequences that are much worse than the galvanic connection in which copper is installed after the lead.

48

# **A White Paper Proposal to Study the Effects of External Currents and Dissimilar Metal Contact on Corrosion and Metals Release from Lead Service Lines**

Prepared by

**HDR Engineering  
Bellevue, Washington**

And

**The Cadmus Group, Inc.  
Arlington, VA**

## **ABSTRACT**

The suggested study design is a series of short-term laboratory-based testing protocols designed to identify whether grounding and/or galvanic currents can have a significant and prolonged impact on metals release from lead service lines (LSLs) and leaded-brass appurtenances. This determination would be made using test rigs where different forms of grounding currents (AC vs. rectified) can be impressed on both scaled and unscaled LSLs, while the internal surface potential of the pipe is monitored. Galvanic currents would be generated using the coupling of different lengths of copper tubing to the LSLs while the surface potential is measured. The testing described herein is not intended to replicate actual distribution system conditions, but rather to explore a series of scenarios where the highest possible metal release and greatest conceivable LSL surface effects are generated. If the findings of this study are negative, there will be a strong basis for discounting the claims and concerns relative to accelerated metal release associated with partial lead service line replacement (PLSLR). If the findings are positive, the study could serve as a foundation and starting point for field tests that explore grounding and galvanic effects in the distribution system with greater similitude. The advantages of the protocols described here are they are short term and relatively low cost.

## **INTRODUCTION**

The recent DC WASA experience relative to LSL replacement indicates that PLSLR does not exacerbate lead-release rates, and can in fact reduce overall drinking water lead concentrations in the home. While this evidence appears strong; there remains a debate about the potential galvanic effects associated with replacing a portion of the old LSL with new copper tubing. Claims have appeared in both the press and scientific

49

publications suggesting that galvanic impacts related to PLSLR, as well as galvanic impacts on leaded-brass appurtenances, may accelerate lead release in DC homes. If so, this may negate all, or at least a portion, of the potential benefit associated with the PLSLR program.

There also remains a controversy about the effect of common grounding currents on the corrosion of LSLs. Some researchers have suggested these currents may be responsible for some of the abnormally high lead-release levels observed in isolated homes. By extension, it can be assumed that if grounding currents are important, at least a portion of the randomness associated with observed lead levels may be related to the presence of different magnitude grounding currents.

The purpose of the research described in this white paper proposal is to establish under controlled laboratory conditions the absolute magnitude of the corrosion impacts potentially associated with both grounding currents and galvanic coupling to lead service lines. It is important to note that while the proposed mechanisms of the galvanic and/or impressed current influence are plausible, and anecdotal evidence is supportive, it has not been clearly demonstrated that either grounding currents or galvanic coupling can in fact meaningfully increase lead release rates. The research proposed here would explore laboratory-generated worst-case situations where the respective impacts on LSLs, if they exist, can be documented and quantified. This study is not intended to duplicate actual field conditions where a PLSLR has occurred, or explore grounding currents in an existing home. Rather, this research is intended to demonstrate whether the respective phenomena can in fact accelerate lead release, or not. If a meaningful impact cannot be demonstrated under conditions designed to exacerbate lead release, then further study in the field is likely unwarranted. In short, if we cannot in this research demonstrate a meaningful impact, than conditions in the DC homes and the distribution system, which will be less challenging than the laboratory test conditions, are not likely to be contributing to accelerated lead release.

This research would not attempt to correlate laboratory experience with field conditions. It is beyond the recommended scope of work to define how differences in soil resistivity, passivation states of copper tubing, or quality of plumbing fabrication may influence the respective current impact. The testing described here is short-term, inexpensive and designed to answer the question: can grounding and/or galvanic currents meaningfully contribute to lead release?

## GROUNDING EFFECTS

### *Background*

Although this topic has been researched extensively over the past decade, there is still considerable debate about the impact of externally-imposed grounding currents on the electrochemistry of interior surfaces of domestic plumbing. The bulk of available research has focused on copper tubing – largely ignoring grounding impacts on lead service lines. While some research has suggested an important internal corrosion role for

50

grounding currents (Bell, 1995; Bell, 1998), other laboratory simulations and field tests have discounted them relative to copper release and associated water quality effects (AWWARF, 1996). The principal issue largely remains: does a current flowing in the pipe wall, and exiting the pipe via an external connection (grounding circuit), change the electrical character of the internal pipe surfaces? If it does, a variety of corrosion and water quality impacts are to be expected, including accelerated metal release. However, an absence of a measurable electrical change on the internal surface would mean the grounding circuit is irrelevant to the internal corrosion processes.

At first glance, it seems intuitive that imposing a (grounding) current on a buried pipe would change the surface potential of the internal and external surfaces. This is certainly true of the external surfaces as the current is dissipated to ground. However, internally, unless some portion of the grounding current is lost to the electrolyte (water in the pipe), these surfaces will show no change in surface potential relative to the water contacting them. In effect, imposing an external current on the pipeline changes the potential of all surfaces and everything in contact with the pipe. Internally, however, the surface potential relative to the electrolyte (which determines corrosion rates) may not change substantially since the electrolyte potential has also been shifted an amount equal to the internal surface.

An important component of the study described in this white paper is an electrochemical investigation of the interior surfaces relative to simulated grounding currents on both heavily scaled and non-scaled LSLs. The objective is to demonstrate under controlled conditions whether it is possible to create a grounding scenario that accelerates internal metal release, and to extrapolate the relevance of those conditions to actual household plumbing practices. Quantifying the actual interior surface potential change vis-à-vis the electrolyte (water) of these pipes is key to assessing grounding current impacts. Any meaningful change in the corrosion condition of the internal surface will be reflected by a substantial change in surface potential, which under the appropriate laboratory conditions can be monitored with a high degree of accuracy ( $\pm 0.1$  mV).

### ***Research Approach***

A flow-through recirculation loop consisting of DC WASA lead service-line segments, water reservoir, flow control and pumping hardware would be employed for this testing. The LSL segments would be modified to accept high impedance reference electrodes penetrating the pipe wall at multiple locations along its length. The electrodes would monitor surface potential on the interior of the pipe relative to the electrolyte, yet allow for pipeline pressurization.

Internal surface potential along the pipeline would be monitored, while different current forms, amperages, voltages and grounding scenarios are applied to the test pipes. At a minimum, the testing criteria would include the following:

Impressed grounding current forms	<ul style="list-style-type: none"> <li>• Full wave AC</li> <li>• Half wave rectified</li> <li>• DC</li> </ul>
Voltage range	0 – 220 Volts
Current range	0 – 20 Amps
Grounding scenarios	<ul style="list-style-type: none"> <li>• Single point ground</li> <li>• Multi-point ground along pipe length</li> <li>• Variable resistance reservoir ground: <i>By providing a current path from the pipe wall through the electrolyte to ground, it will be possible to dissipate some of the applied external current to the interior surface of the pipe. The variable resistance ground to the electrolyte reservoir will make it possible to balance current dissipation between external and internal surfaces.</i></li> </ul>

Because of the capacitance effects of a corrosion scale relative to alternating current, it will be important to evaluate grounding impacts on both heavily-scaled and non-scaled LSLs. This study design includes testing on these surfaces, as well as on leaded-brass appurtenances such as water meters. Lead service-line test segments and brass appurtenances will be obtained directly from DC WASA. The water meter testing will be conducted in a loop arrangement similar to the lead service-line test rig; however, due to the geometry of the water meter it will likely be possible to insert only a single reference electrode into the body of the meter.

The primary impact of the grounding current would be assessed via internal surface potential changes on the LSL and brass water meters. Potential impact on lead release would be confirmed via analysis of lead concentrations in the recirculation water. Both dissolved and particulate lead levels could be determined. The water chemistry used in the recirculation loop would consist of a synthetic water targeting the basic inorganic constituents of the DC WASA system.

## GALVANIC EFFECTS

### *Background*

Unlike the debatable and uncertain impacts of grounding currents on internal corrosion, galvanic related corrosion impacts associated with dissimilar metals coupling has been theoretically quantified and measured in both the laboratory and the field (Reiber, 1991). The magnitude of the galvanic impact relates directly to the electro-activity of the anodic and cathodic surfaces, and their respective sizes and geometries.

The relevance to LSL replacement is straightforward: a partial replacement of a portion of the lead line with a new copper service line creates a relatively strong galvanic couple

52

with an initial Cu/Pb electromotive difference in the 50 – 100 mV range. If the potential of the entire remaining section of lead service line were shifted in the anodic direction by this amount, clearly there would be a substantial acceleration of the corrosion rate and associated lead-release rates. Yet, in practice, we find that a PLSLR does not usually increase lead release (DC WASA, 2004). Moreover, in other studies that have assessed lead release from intact and aged LSLs electrically connected to copper tubing for many years, no meaningful increase in lead-release rates was identified (HDR Engineering, 1994).

The answer to this conundrum likely relates to the respective geometries of the anodic and cathodic surfaces of the galvanic couple. Because sequential pipelines (LSL to copper tubing) are connected at only a single location, it is likely that only a small portion of the LSL is polarized by the galvanic current. And, given the relatively rapid rate at which both copper and lead surfaces passivate, the duration of the polarization may be relatively brief. Hence the galvanic effect may be very short term.

In the DC WASA case, however, the passivating corrosion scales formed on the LSLs in the presence of chloramines are clearly less protective than those formed in the presence of free chlorine. It will be important to distinguish between the galvanic impact associated with these different forms of corrosion scales.

### ***Research Approach***

This portion of the recommended research would explore galvanic coupling related to PLSLR in a laboratory context where the electrochemical effects of galvanic coupling can be monitored and assessed relative to geometry and passivation state of the respective lead and copper pipes. The practical objective of this effort is to assess the magnitude and duration of the galvanic impacts associated with PLSLR.

As in the grounding current portion of this study, it would be possible to assess the galvanic impact of copper and lead service-line coupling by monitoring the surface potentials along the lengths of the respective pipe sections, especially in the immediate proximity of the contact point between copper and lead lines. A recirculation test loop consisting of water reservoir, pumping and flow control equipment, and different lengths of copper and LSLs (LSLs to be provided by DC WASA) would be constructed. High impedance reference electrodes would be inserted along the lengths of both copper and lead lines, and the surface potential of the respective lines would be monitored at the initial coupling and for extended passivation periods thereafter. Water chemistry impacts relative to galvanic coupling would also be explored, including assessing the relative impacts of chlorine and chloramine across a typical distribution system concentration range.

To ensure the maximum galvanic driving potential, testing could be conducted using both scaled LSLs from the DC WASA system, and LSLs that have been scoured to remove any existing corrosion scale. The copper tubing used in these tests would consist of new tubing polished to ensure an electro-active surface. If the galvanic testing using LSLs

shows a positive result, similar tests could be conducted using leaded-brass water meters as the anodic surface.

Given the geometry of the service lines, the area of greatest galvanic influence would be in close proximity to the coupling point. A special rig with a reference electrode that can be moved and placed with precision along the bore of the pipes would be used to quantify both the magnitude and the area of influence. This research could quantify the LSL portion that is galvanically activated, the duration of activation, and associated lead-release rate increases.

### **RESEARCH EFFORT AND SCHEDULE**

Grounding and galvanic current testing could be conducted in the HDR Engineering Water Quality and Corrosion Services Laboratory in Bellevue, Washington. The HDR facility already has available the necessary electrochemical and pipe loop equipment to conduct this work. Analytical work (i.e. water chemistry) will be performed internally.

The total estimated research effort (manpower) for HDR is approximately 400 hours, broken down as follows:

Task	Effort	HDR Rate	Hours	Totals
Develop detailed study plan	Research Technician	\$85.00	20	\$1,700
Develop detailed study plan	Principal Investigator	\$207.00	20	\$4,140
Laboratory set-up	Research Technician	\$85.00	100	\$8,500
Testing	Research Technician	\$85.00	100	\$8,500
Testing	Principal Investigator	\$207.00	50	\$10,350
Report preparation	Principal Investigator	\$207.00	50	\$10,350
EPA coordination and management	Principal Investigator	\$207.00	50	\$10,350
Clerical support	Project Controller	\$85.00	10	\$850
Subtotal			400	\$54,740
Subcontractor Handling Costs (4.4%)				\$2,410
Total for Subcontractor HDR (approx)			400	\$57,150

The budget above does not reflect the hours needed for Cadmus staff to process contract paperwork, work with HDR to develop an acceptable QA/QC plan, oversee the work, and review the work products. The estimated Cadmus hours needed for these tasks are 60 to 120 at an average hourly rate of approximately \$75 per hour, for an estimated cost of \$4,500 to \$9000. Thus, the total estimated cost for this work ranges from \$61,500 to \$66,000.

The overall schedule for completion is approximately three months from notice to proceed, although this is dependent on time needed for approval of the QA/QC plan.

As noted earlier, the proposed project is not a major research effort. It is intended instead to quickly identify whether or not there is a serious problem associated with galvanic coupling and grounding currents relative to LSLs. If the project demonstrates an effect, further research will be needed to quantify the extent of the problem in the distribution system, including extensive field work. If, on the other hand, the project does not identify a significant impact associated with grounding or galvanic currents, it would then be relatively clear that concerns about these electrochemical effects are out of proportion, and likely not a serious contributor to lead release in the DC WASA system.

55

## References

Bell, G.E.C., "Observation on the Effect of Grounding on Water Piping,"  
CORROSION/95, Orlando, 1995

Bell, G.E.C., "Effects of Grounding on Metal Release in Drinking Water," AWWA  
Inorganics Contaminants Workshop, San Antonio, 1998

AWWA Research Foundation, "Electrical Grounding, Pipe Integrity and Shock Hazard,  
1996

Reiber, S., "Galvanic Stimulation of Lead/Tin Solder Sweated Joints," Journal AWWA,  
1991

DC WASA, personal communication with Richard Giani, 2004

HDR Engineering, Corrosion Control Assessment for the City of Tacoma, 1994

## **Progress Report**

# **Effects of External Currents and Dissimilar Metal Contact on Corrosion and Metals Release from Lead Service Lines**

Prepared by

**HDR Engineering**

and

**The CADMUS Group**

**July , 2005**

is in excess of 500 - 600 mV per decade of current shift. Overall, this explains, at least in part, why the galvanic coupling has little apparent effect on passivated lead surfaces.

**Metal Release.** Metal release from unpassivated LSL sections (scale removed) is exceptionally high when galvanically coupled. Metal release from passivated LSL sections is exceptionally low, even when galvanically coupled. This may be because the oxidized metal generated in the galvanic process is largely retained within the corrosion scale.

**Area of LSL Influence.** The galvanic area of influence on an LSL specimen, even when unpassivated, is relatively small – possibly less than the first few feet of pipe extending away from the point of coupling. As the LSL passivates the area of galvanic influence decreases. On a well-passivated LSL the galvanic area of influence is likely limited to at most a few inches of pipe in the immediate vicinity of the coupling.

**Length of Copper Pipe.** Anode/cathode ratio is relatively unimportant on well-passivated LSL surfaces. This means that even an exceptionally long length of copper pipe connected to a partial LSL does not elevate the galvanic effect.

**Chlorine Impacts.** A free-chlorine residual does elevate the galvanic effect by accelerating the cathodic current exchange process. Conversely, chloramine has a lesser galvanic impact than free chlorine.

**Conductivity Effects.** The area of galvanic influence on the LSL specimen is expanded as the conductivity of the electrolyte (water) increases. DC WASA distributes a low conductivity water (< 120 microSiemens), which may in part explain the minimal galvanic impacts observed. A conductivity increase of 100 microSiemens would double the area of LSL galvanic influence.

**Dielectric Effects.** While galvanic impacts relative to DC WASA partial LSLs are likely minimal, any break in electrical continuity between the copper and LSL lines effectively eliminates the potential for a galvanic effect. In short, a conventional plumbing dielectric junction removes even the minor corrosion risks associated with galvanic coupling.

## Continuing Research

**Galvanic Impacts.** The remaining portion of the galvanic research is focused on the assessment of chloramine effects on passivated LSLs, and how changes in orthophosphate inhibitor application coupled with chloramines exposure may alter galvanic processes and metal release.

**Grounding Currents.** Does a current flowing in the pipe wall, and exiting the pipe via an external connection (grounding circuit), change the electrical character of the internal pipe surfaces? If it does, a variety of corrosion and water quality impacts are to be expected, including accelerated metal release. This is the grounding current scenario that is typical of the electrical systems in many older households. This portion of the study will be an electrochemical investigation of the interior LSL surfaces relative to simulated grounding currents on both heavily scaled and non-scaled specimens. The objective is to demonstrate under controlled conditions whether it is possible to create

grounding scenarios that accelerate internal metal release, and to extrapolate the relevance of those conditions to actual household plumbing practices.

A flow-through recirculation loop consisting of DC WASA lead service-line segments, water reservoir, flow control and pumping hardware will be employed for this testing. The LSL segments will be modified to accept high impedance reference electrodes penetrating the pipe wall at multiple locations along its length. The electrodes will monitor surface potential on the interior of the pipe relative to the electrolyte, yet allow for pipeline pressurization. Internal surface potential along the pipeline will be monitored, while different current forms, amperages, voltages and grounding scenarios are applied to the test pipes. Following experimentation with LSL sections, a limited grounding current test protocol will be conducted using leaded brass water meters and the same impressed current testing regimen.

This portion of the study will require 2 to 3 weeks of laboratory time.

Draft

59

**SUPPLEMENTAL QUALITY ASSURANCE PROJECT PLAN (QAPP)  
FOR STUDY OF THE EFFECTS OF EXTERNAL CURRENTS AND  
DISSIMILAR METAL CONTACT ON CORROSION AND METAL  
RELEASE FROM LEAD SERVICE LINES**

**Submitted to:  
George Rizzo  
Work Assignment Manager  
U. S. Environmental Protection Agency**

**Work Assignment 2-47, Task 4 of EPA Contract #68-C-02-069  
*AMENDMENT 1***

**Prepared by:  
The Cadmus Group, Inc.  
57 Water Street  
Watertown, MA 02472**

**June 13, 2005**

68

For the grounding current experiments, surface potential along the pipeline will be monitored while various voltages and grounding scenarios are applied to the pipe. The scenarios to be tried include:

**Table 1: Experimental Scenarios**

Impressed grounding current forms	Full wave AC Half wave rectified DC
Voltage range	0 – 220 Volts
Current range	0 – 20 Amps
Grounding scenarios	<ul style="list-style-type: none"> <li>• Single point ground</li> <li>• Multi-point ground along pipe length</li> <li>• Variable resistance reservoir ground: <i>By providing a current path from the pipe wall through the electrolyte to ground, it will be possible to dissipate some of the applied external current to the interior surface of the pipe. The variable resistance ground to the electrolyte reservoir will make it possible to balance current dissipation between external and internal surfaces.</i></li> </ul>

Scale can have a capacitance effect on alternating current, so both scaled and non-scaled pipes will be tested.

A brass water meter will also be tested to determine the effects of grounding currents on brass appurtenances. The meter will be obtained from WASA and will be outfitted with a single reference electrode.

The effect of grounding currents of lead service lines and brass water meters will be determined both by measuring the inner surface potentials and by measuring both dissolved and particulate lead in the water.

The other portion of the project will involve measuring the magnitude and duration of galvanic effects resulting from coupling of lead and copper pipes during PLSLR. The same type of flow-through recirculation loop will be used, this time coupling the lead service lines with copper pipes. Reference electrodes will be placed along the length of both the copper and lead pipes. A special electrode rig will be used in the near vicinity of the galvanic joint that will be capable of measuring with precision the distance from the joint and the potential.

Project	Contract No. 68-C-02-069, WA 2-47
Revision Number	Version 1
Date	June 13, 2005
Page	9 of 17

61

Potential measurements will be taken for extended times to allow for passivation. Both scaled and unscaled lead lines will be used to examine the differences that scale makes. The effect of water chemistry will also be examined by performing the experiment separately with chlorine and chloramines as the disinfectant.

The extent of the galvanic activation, its duration, and the increase in lead release as a result will all be measured as part of this experiment.



### **A7. Quality Objectives & Criteria for Measurement Data**

The purpose of this project is to evaluate the level of corrosion of lead service lines caused by galvanic corrosion and grounding currents. This evaluation includes the following goals:

- Measure the surface potential and corrosion rate of lead service lines impressed with a grounding current at a single point.
- Measure the surface potential and corrosion rate of lead service lines impressed with a grounding current at multiple points.
- Measure the surface potential and corrosion rate of lead service lines impressed with a variable resistance reservoir ground.
- Measure the surface potential and corrosion rate of brass water meters impressed with a grounding current at a single point.
- Measure the surface potential and corrosion rate of brass water meters impressed with a grounding current at multiple points.
- Measure the surface potential and corrosion rate of brass water meters impressed with a variable resistance reservoir ground.
- Measure the surface potential of unscaled lead service lines with a galvanic couple to a copper line.
- Measure the surface potential of scaled lead service lines with a galvanic couple to a copper line.

### **A8. Special Training Requirements/Certifications**

No specific training will be conducted for this experiment. The two HDR personnel, Michael Britton and Sidney Hendrickson, Ph.D., who will oversee daily operations of the experiments, both have extensive experience in the water industry and with running pilot scale research experiments.

<i>Project</i>	<i>Contract No. 68-C-02-069, WA 2-47</i>
<i>Revision Number</i>	<i>Version 1</i>
<i>Date</i>	<i>June 13, 2005</i>
<i>Page</i>	<i>10 of 17</i>

62

## A9. Documents and Records

The Cadmus work assignment manager will distribute this QAPP and any revisions to each individual listed on the distribution list and to all personnel involved in this project.

Project personnel will keep:

- Field notes;
- Shipping receipts;
- Chain of custody forms;
- Raw water data and quality control (QC) sample records; and,
- Instrument, equipment, and model calibration information.

All standard sampling will be done on site. Weekly samples, however, will be sent off site as a QC check to the on-site measurements. Shipping receipts and chain of custody forms for these samples will be kept.

Cadmus will submit a Draft Report to the EPA Work Assignment Manager for review. The report will be submitted electronically and in hard copy as stated in the attached work plan. The report will include data collection methodologies, an analysis of data collection results, and a description of any necessary corrective actions. Cadmus does not anticipate submission of actual field logs, sample preparation and analysis logs, instrument printouts, QC sample records or receipts, or the results of calibration checks, but will include this information in the final project report, along with any revisions suggested by the EPA Work Assignment Manager.

Cadmus will keep all documents and records related to this project at its Arlington, Virginia office. Documents and records will be kept for the life of the contract under which this project was completed, or in accordance with any applicable U.S. government record retention policies, whichever is longer.

} \* ↑  
??

## B1. Sampling Process Design

Table 2 lists the parameters that will be measured, the equipment that will be used, and the frequency of these measurements. The primary measurement that will be taken is surface potentials. Surface potentials will be measured on the interior surface of the pipe or water meter, depending on the experiment, using a multimeter coupled to saturated calomel and Ag/AgCl reference electrodes. Corrosion rates on surfaces with impressed currents will be measured using an automated potentiostat. Lead and copper concentrations will be measured using a colorimeter.

<i>Project</i>	<i>Contract No. 68-C-02-069, WA 2-47</i>
<i>Revision Number</i>	<i>Version 1</i>
<i>Date</i>	<i>June 13, 2005</i>
<i>Page</i>	<i>11 of 17</i>

63

**Table 2: Sampling Parameters and Equipment**

Parameter	Equipment	Sampling Frequency
Surface Potential	Fluke Multimeter coupled to a saturated calomel and Ag/AgCl reference electrode.	Continuous
Corrosion Rate	Gamry Automated Potentiostat	Twice a day or more often as needed
Lead	Hach LeadTrak (TM)	As needed, several times a day
Copper	Hach CuVer (R)	As needed, several times a day

## B2. Sampling Methods

Staff are aware of the common routes of exposure when sampling, and are trained in the proper use of safety equipment and protective clothing.

Sampling will be conducted by Michael Britton and Sidney Hendrickson, Ph.D., who have extensive experience with the methods involved. Samples will be drawn from the reservoir as well as the pipe loop during circulation. Both the reservoir and pipe loop will be outfitted with sample taps. Samples for metal analysis will be drawn from the sample taps after one minute of flushing. Containers will then be rinsed with sample and discarded before the container is filled with sample to be measured. Standard methods and practices will be used for all sample gathering, preservation, packaging, and transport.

## B3. Sample Handling and Custody

All sample sets will be accompanied by a chain-of-custody form. An example of the form that will be used is attached to this QAPP. When the possession of samples is transferred, both the individual relinquishing the samples and the individual receiving the samples will sign, date, and note the time on the chain-of-custody document. The original form of the chain-of-custody record will accompany each shipment. A copy will be retained by a representative of the sampling team.

<i>Project</i>	<i>Contract No. 68-C-02-069, WA 2-47</i>
<i>Revision Number</i>	<i>Version 1</i>
<i>Date</i>	<i>June 13, 2005</i>
<i>Page</i>	<i>12 of 17</i>

Parameter	Analytical Method	Detection Limit
Copper and Lead (for QC)	US EPA 200.8	0.003 µg/L (Cu) and 0.005 µg/l (Pb)

## B5. Quality Control

Corrective action procedures are described in Section 10.4.2 of the Cadmus QMP (CGI -8.21; Revised).

Table 4 provides the data quality indicators and the determination methodology that will be used for the samples collected during this study.

Table 4: Acceptance Criteria for Primary Data

Data Quality Indicator	Definition	Determination Methodology	
Precision	Measure of agreement among repeated measurements of the same property under identical or substantially similar conditions.	<i>Split samples</i>	Daily samples will be split and measured for lead and copper
		<i>Conforming to ASTM techniques</i>	Electrochemical techniques will conform to ASTM G3-74
Bias	The systematic or persistent distortion of a measurement process that causes errors in one direction.	Standard sampling equipment and procedures will be used.	
		<i>Blanks</i>	Blanks of Milli-Q water will be analyzed for lead and copper
		<i>Calibration with standards</i>	Manufacturer provided standards will be measured and used to prepare calibration curves for lead and copper each day.

Project	Contract No. 68-C-02-069, WA 2-47
Revision Number	Version 1
Date	June 13, 2005
Page	14 of 17

65

Sampling personnel will adhere closely to all sample storage, preservation and handling protocols. Sample bottles and preservatives required by the analytical method will be used. Sample collection time will be included on the chain-of-custody form so that holding times will not be exceeded.

#### B4. Analytical Methods

To obtain reliable and reproducible results, all laboratory analyses will adhere to prescribed analytic methods. All analyses will be performed on-site by HDR personnel experienced with the procedures. To verify measured lead and copper concentrations, weekly lead and copper samples will be split and duplicate samples will be sent to North Creek Analytical in Bothell, WA. North Creek Analytical is certified by EPA and the state of Washington to perform lead and copper analyses. Results will be reported back to the on-site personnel, so that gaps in the QA/QC can be detected and corrected.

QA oversight for sampling will be provided by HDR's Dr. Reiber. In the event that a sample is invalidated due to laboratory or handling error, HDR and Cadmus will take the necessary corrective action including collecting another sample at the same sampling location using an identical procedure.

Table 3 provides the analytical methods, detection limits, and holding times that will be used for the samples collected during this study.

**Table 3: Analytical Methods and Detection Limits**

Parameter	Analytical Method	Detection Limit
Surface Potential	Pipe section flow cell method (AWWARF 1996), where applicable will conform to ASTM G3-74	0.1 mV
Corrosion Rate	Potentiodynamic sweep, will conform to ASTM G3-74	0.1 mV
Lead	Hach LeadTrak	0.004 mg/L
Copper	Hach Method 8506	0.04 mg/L

<i>Project</i>	<i>Contract No. 68-C-02-069, WA 2-47</i>
<i>Revision Number</i>	<i>Version 1</i>
<i>Date</i>	<i>June 13, 2005</i>
<i>Page</i>	<i>13 of 17</i>

666

## TECHNICAL PROGRESS REPORT

EPA Contract No. 68-C-02-069

Work Assignment No. 2-47

District of Columbia Water System - Direct Implementation Support

May 2005

---

<b>Work Assignment Manager:</b>	George Rizzo
<b>Effective Date:</b>	August 1, 2004
<b>Completion Date:</b>	July 31, 2005
<b>Subcontractors:</b>	HDR Engineering, Anne Camper, Ph.D., Gregory Korshin, Ph.D., Virginia Military Institute (VMI)

---

### Summary of Activities for Current Month:

#### *Task 1: Development of Work Plan*

- Cadmus performed routine work assignment management activities, including writing and submitting the monthly progress report, tracking budget expenditures, and managing the subcontractors.
- Cadmus continued developing quality assurance plans for the new studies in Amendment 1 that require collection of original data.

#### *Task 2: Sanitary Survey of the Washington Aqueduct*

- None.

#### *Task 3: Sanitary Survey of Consecutive Water Systems*

- None.

#### *Task 4: Review of Corrosion Control Treatment Recommendations*

- Cadmus and its subcontractor, Dr. Steve Reiber of HDR Engineering, continued to review data collected from the electro-chemical pipe loop studies and discussed results with the DC Water and Sewer Authority (WASA).

67

*Task 3: Sanitary Survey of Consecutive Water Systems*

- Upon receipt of comments from the EPA WAM on the sanitary survey report developed under a previous work assignment, Cadmus will revise the report.

*Task 4: Review of Corrosion Control Treatment Recommendations*

- Cadmus and its subcontractor, Dr. Reiber, will continue to review data collected from the electro-chemical pipe loop studies and discuss results with DC WASA personnel.
- Cadmus and its subcontractors will participate in the Technical Expert Working Group (TEWG) conference call scheduled for July 3, 2005, and prepare a conference call summary. Cadmus will participate in additional TEWG conference calls as scheduled by the EPA WAM.
- Cadmus and its subcontractor, Dr. Reiber, will continue writing the interim OCCT report.
- Cadmus and its subcontractor, Dr. Reiber, will continue conducting a study to determine the effects of external currents and dissimilar metals on corrosion and metals release from lead service lines.

*Task 5: Review of the Impact of Corrosion Control Treatment Recommendations on Waste Water*

- Cadmus' subcontractor, Dr. Bott, will continue training VMI students in preparation of Phase III of the study, scheduled to begin in early June 2005.
- VMI students will begin Phase III of the study to be performed on-site at the Arlington County Water Pollution Control Plant.

*Task 6: Review of Sampling Plans for the District of Columbia Distribution System*

- Cadmus will review additional monitoring plans at the direction of the EPA WAM.

*Task 7: Sanitary Survey of the District of Columbia Distribution System*

- Cadmus will continue to conduct follow-up interviews as needed to complete the sanitary survey of the DC distribution system.

*Task 8: Prepare Draft Report of the Sanitary Survey*

- Cadmus will continue preparing the draft report of the sanitary survey.

68

## The Effect of Partial Lead Service Line Replacements on Lead Leaching

Caroline Nguyen, *Virginia Tech*  
 Simoni Triantafyllidou, *Virginia Tech*  
 Jie Hu, *Wuhan University*  
 Marc Edwards, *Virginia Tech*

San Diego, CA  
 June 14, 2009

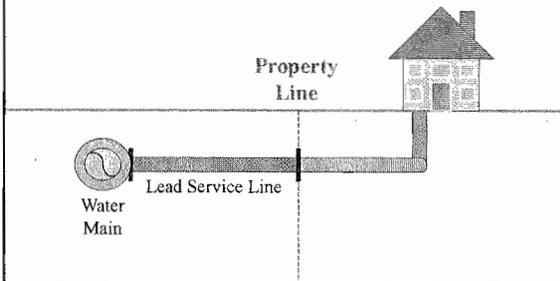


- Cincinnati – lead spikes after partial line replacements; lasted 1-4 weeks
- “But even after 1 year of sampling, partial lead service line replacement did not show an improvement over keeping a complete line in place.”

(Swertfeger et al., 2006)



If utility exceeds 15 ppb AL, partial pipe replacements may be required up to property line.



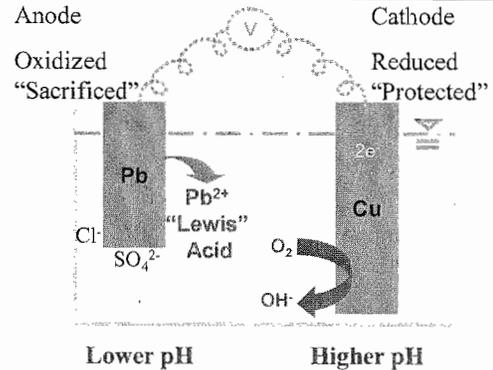
## Boyd et al., 2004

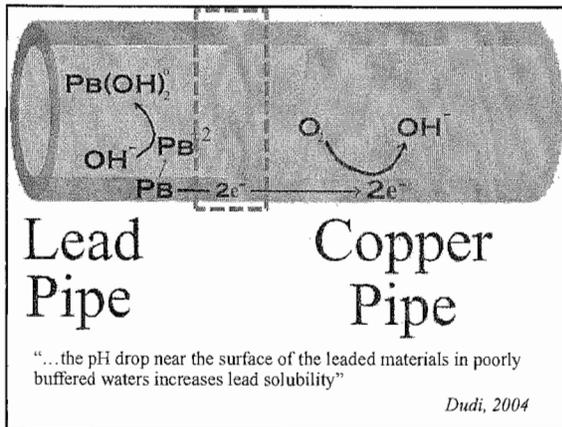
- Only examined cutting of lead pipe
- Observed higher lead release for over 2 weeks
- Intermittent Flow: total Pb > 15 ppb after 2 weeks
- Continuous Flow: total Pb consistently < 15 ppb after 2 days (high flow) or 6 days (low flow)



## Adverse Consequences of Partial Replacements

- Disturbing rust scale (Boyd et al., 2004)
- Galvanic Corrosion (Britton et al., 1981)
- Deposition Corrosion (Britton et al., 1981)



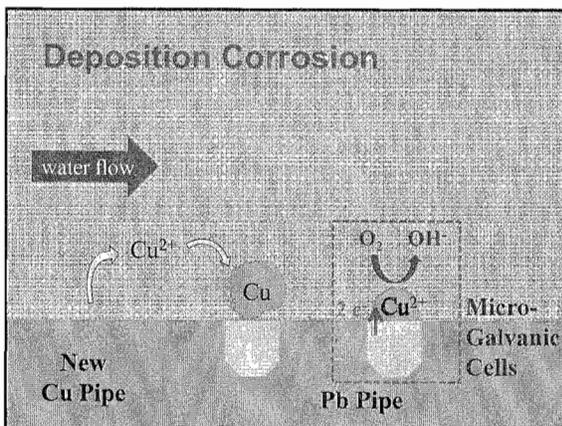


**Galvanic corrosion important for roofs**

Urban rainfall on roofs  
 - Large increase in Pb corrosion rates if Pb connected to Cu

Some increase in marine atmosphere (higher Cl)

(Kucera et al., 1982)



**Britton and Richards, 1984**

- 186 – all or some Pb service lines
- 69 – had at least 1 Cu/Pb connection

**Early work on galvanic corr. and lead**

- “... solution of lead was assisted by contact with other metals” such as copper-lead connections  
 (Wolffhugel, 1887)
- “... in practice, contact with iron pipes, solder, etc., is an important factor in assisting the attack on lead by water.”  
 (Lindsay, 1859)
- “... galvanic action is a most powerful agent in promoting the corrosive action of certain waters upon lead”  
 (Stirling, 1859)

**Britton and Richards, 1984**

- “... abnormally erratic or much higher than normal lead concentrations” when Pb connected to Cu
- “Occasionally the insertion of copper pipe can produce particularly bad results and despite satisfactory pH control it may be impossible to obtain satisfactory samples.”
- “... the contribution to the water lead concentration from the area around the lead/copper junction is obvious.”

10

## What are the practical concerns related to galvanic corrosion and PSR?

- Creation of new Pb/Cu junctions
- Placing copper before lead in flow sequence

Virginia Tech

## Causes for Concern: High CSMR

- English studies measured galvanic current and voltage in connections of lead solder to copper
  - Oliphant (1983) and Gregory (1985)
- Dodrill & Edwards (1995) and Triantafyllidou (2007): more lead with higher chloride and lower sulfate
- Pb action level exceeded when coagulant changed from alum to PACl, isolated cases of lead poisoning

## Scenarios

	Galvanic Junction(s)	Copper Deposition on Lead?
	None	No
	1	No
	2	Yes

## Experimental Plan

- Deposition corrosion from  $\text{Cu}^{2+}$ 
  - Stagnant
  - Flow
- Galvanic corrosion (Pb/Cu)
- Simulated small scale partial replacement

Virginia Tech

## Chloride to Sulfate Mass Ratio (CSMR) Sample Calculation

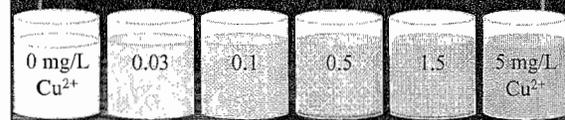
$$\text{Chloride to Sulfate Mass Ratio (CSMR)} = \frac{[\text{Cl}^-]}{[\text{SO}_4^{2-}]} = \frac{10 \text{ mg/L Cl}^-}{20 \text{ mg/L SO}_4^{2-}} = 0.5$$

Virginia Tech

## Experimental Design: $\text{Cu}^{2+}$ Deposition Corrosion

	$\text{Cl}^-$ (mg/L)	$\text{SO}_4^{2-}$ (mg/L)	CSMR	pH	Alkalinity (mg/L $\text{CaCO}_3$ )
High CSMR Water	129	8	16	8.3	10

- Free chlorine and chloramine (4 mg/L  $\text{Cl}_2$ )

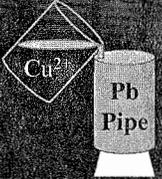


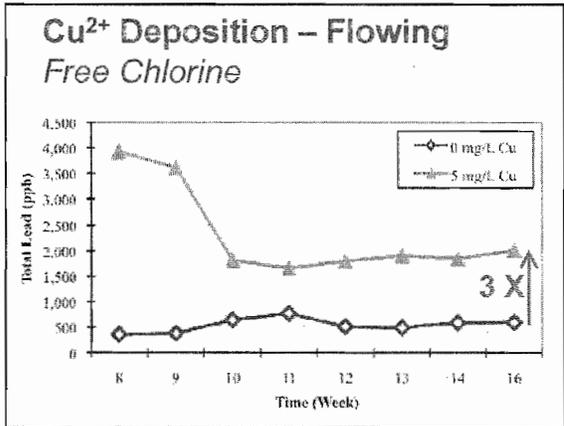
21

### Experimental Design: $\text{Cu}^{2+}$ Deposition Corrosion

**Stagnant:**

- 3 Replicates
- Dump & Fill 3 X/week

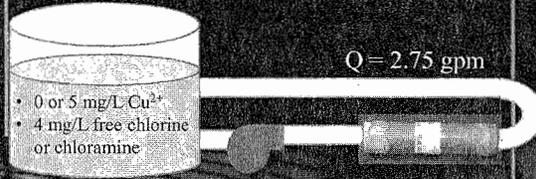




### Experimental Design: $\text{Cu}^{2+}$ Deposition Corrosion

**Flowing:**

- Continuous flow
- Water change once/wk



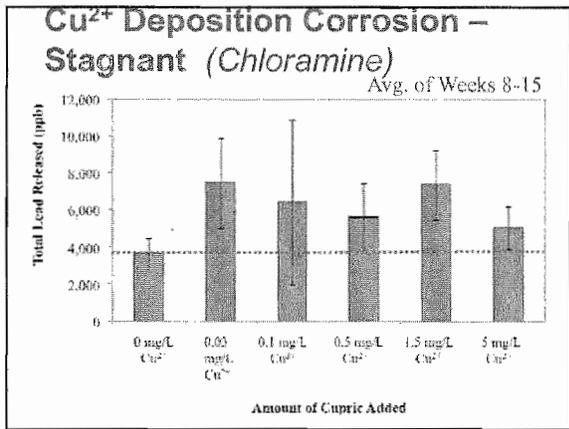
$Q = 2.75 \text{ gpm}$

- 0 or 5 mg/L  $\text{Cu}^{2+}$
- 4 mg/L free chlorine or chloramine

### $\text{Cu}^{2+}$ Deposition Corrosion Conclusions

- Trace levels of  $\text{Cu}^{2+}$  (even 0.03 mg/L) increased lead release from lead pipe w/ no galvanic connection to Cu
- Deposition corrosion significant concern in terms of lead leaching as per prior research
- Putting a copper pipe before a lead pipe in the flow path, as occurs in partial replacement, is a concern

Virginia Tech  
Center for Future

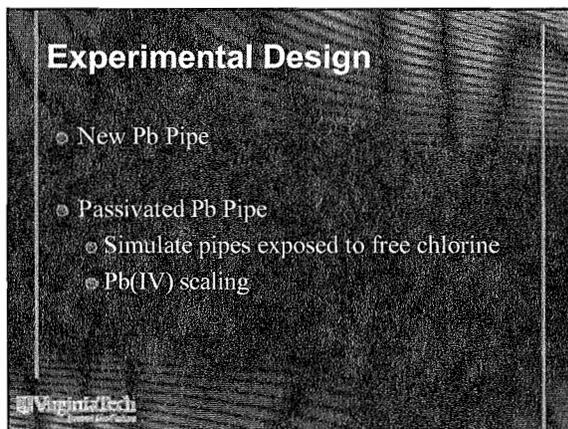
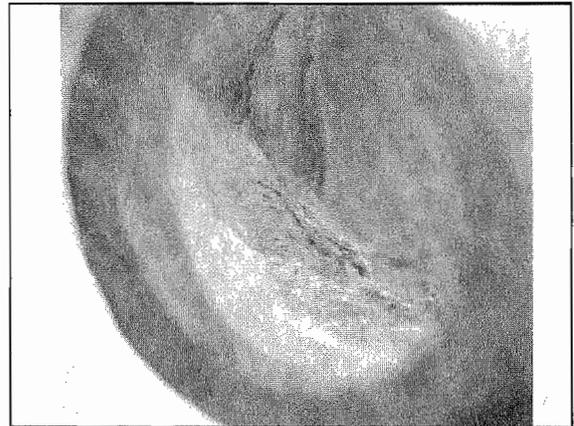
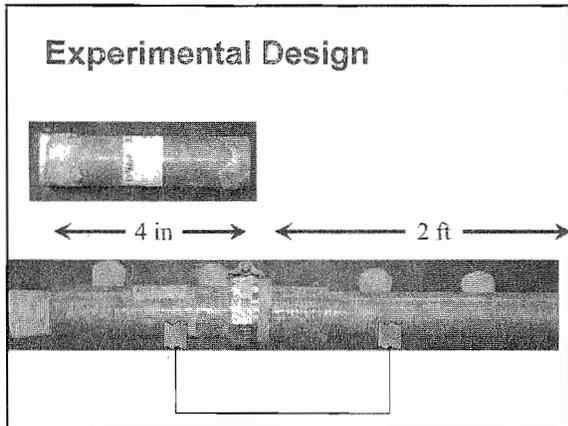


### Mechanisms of Galvanic Corrosion (Pb Pipe – Cu Pipe)

*New vs. Aged Pb Pipe*  
CSMR

Virginia Tech  
Center for Future

72

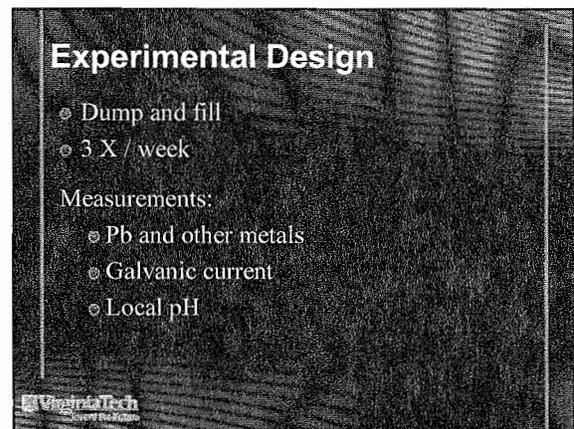
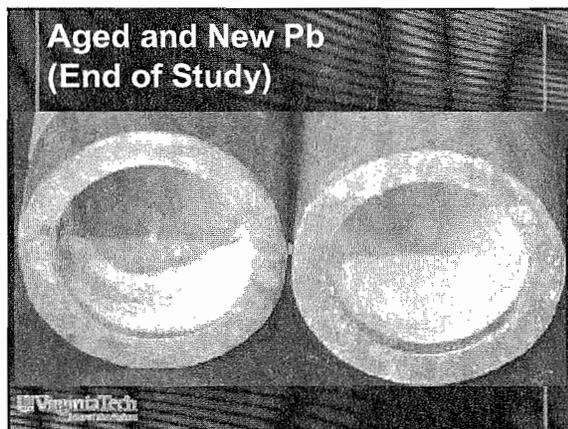


### Water Chemistry

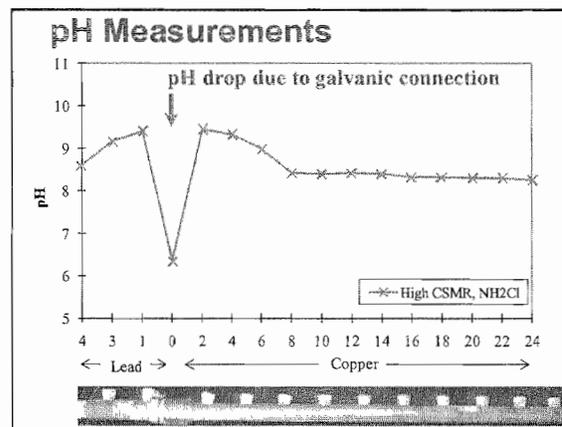
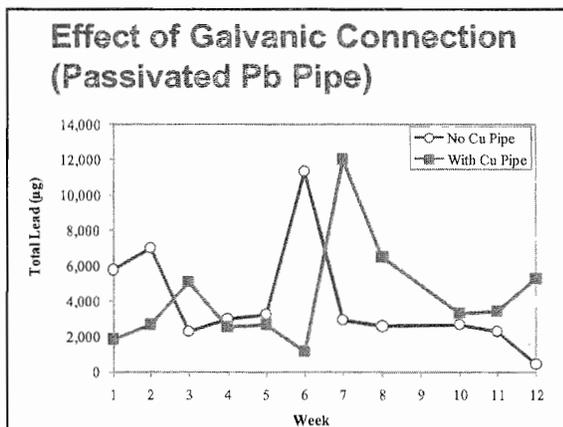
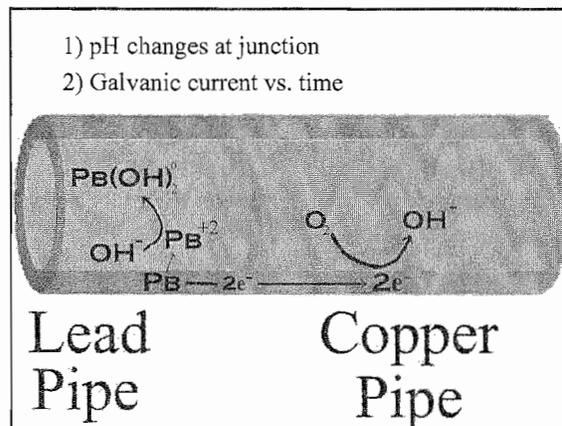
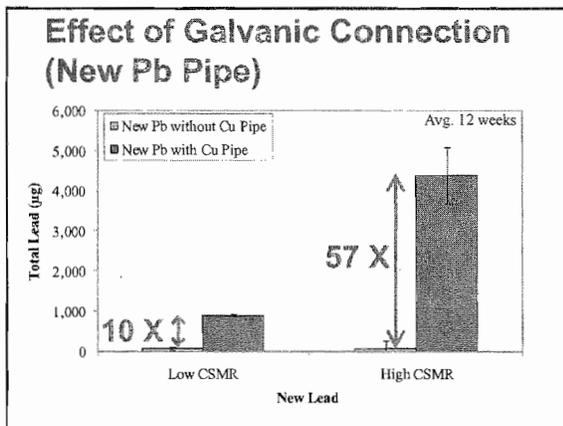
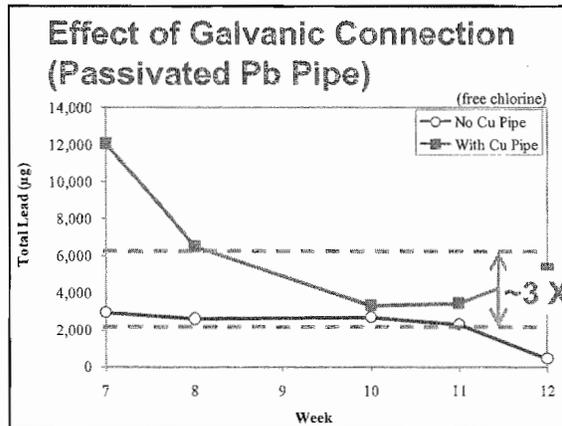
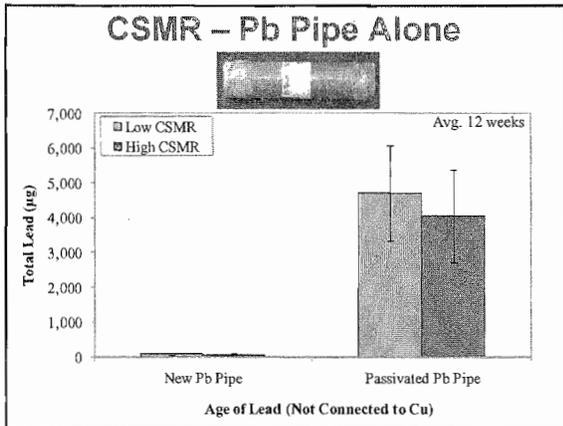
*pH 8.3*

	Cl <sup>-</sup> (mg/L)	SO <sub>4</sub> <sup>2-</sup> (mg/L)	CSMR	Alkalinity (mg/L CaCO <sub>3</sub> )
Low CSMR	22	112	0.2	10
High CSMR	129	8	16	10

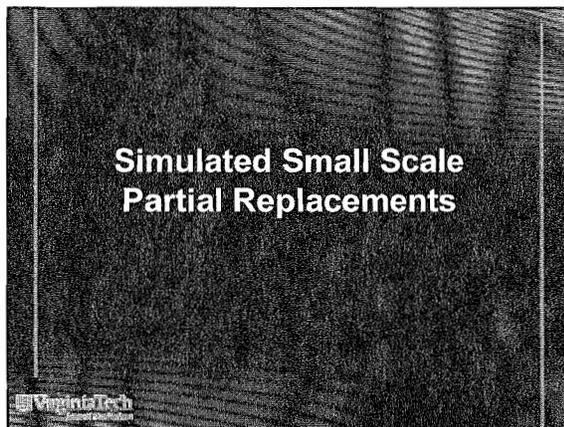
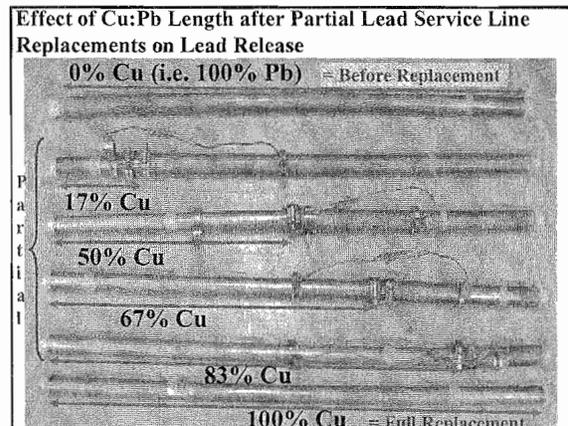
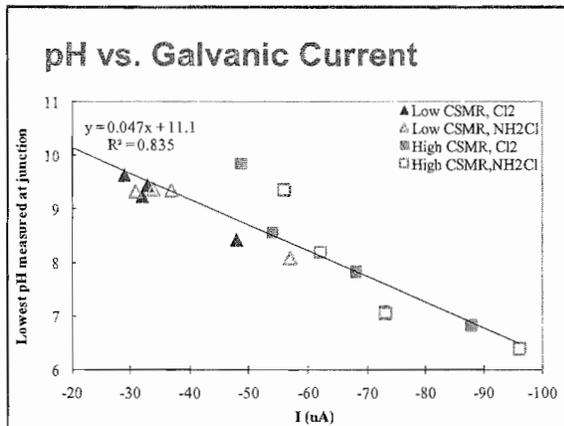
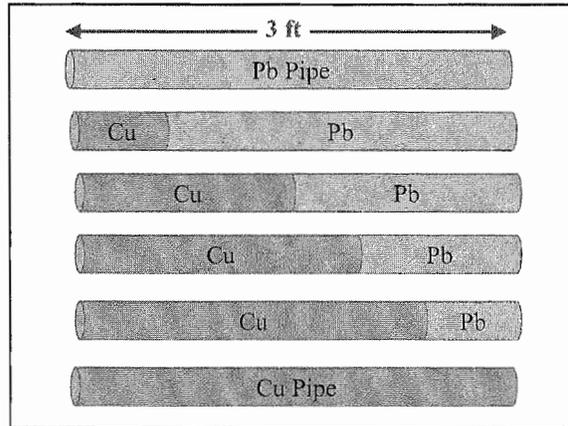
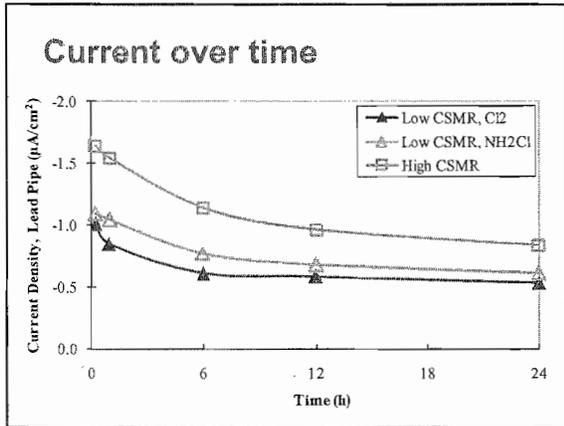
Disinfectants:  
- Free chlorine & chloramine



72



74



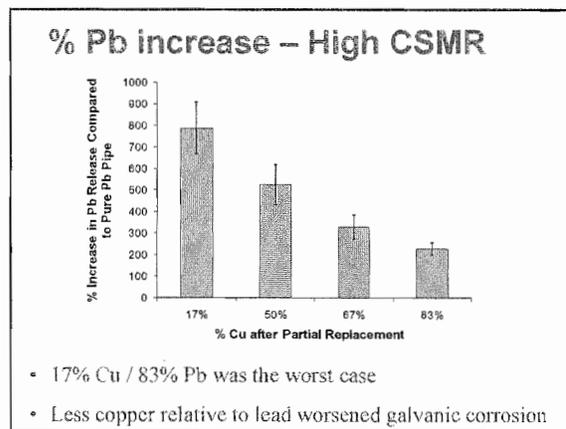
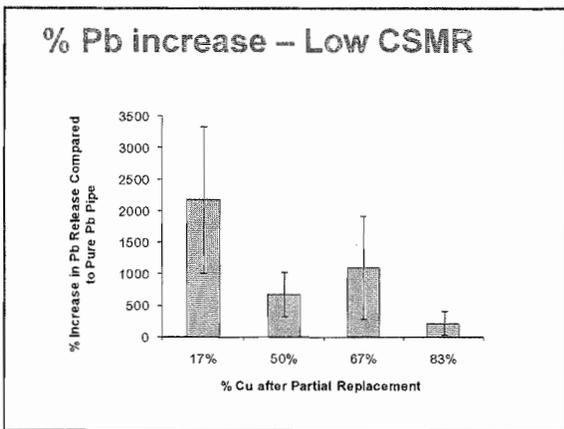
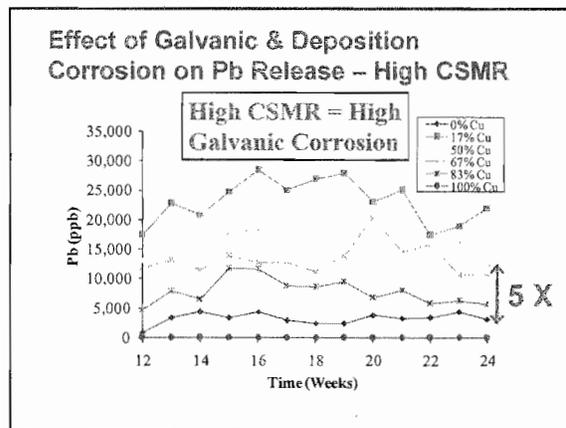
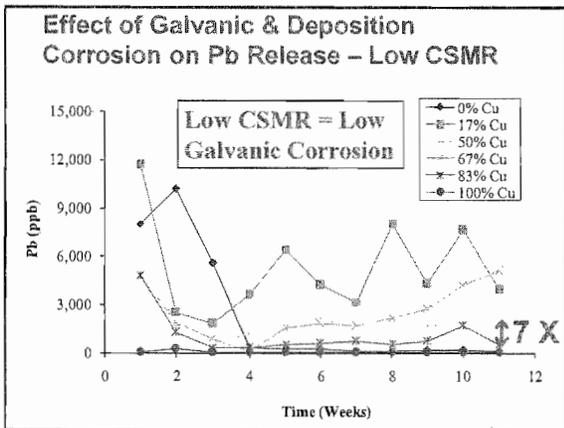
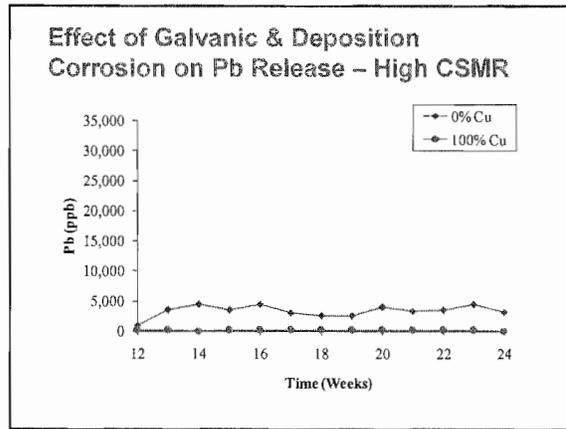
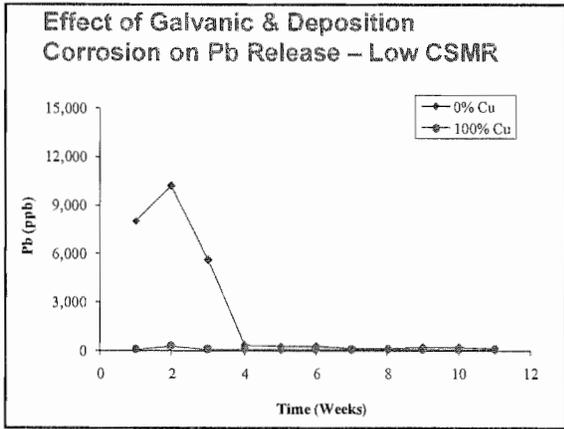
### Water Chemistry

pH 8.0

	Cl <sup>-</sup> (mg/L)	SO <sub>4</sub> <sup>2-</sup> (mg/L)	CSMR	Alkalinity (mg/L CaCO <sub>3</sub> )
Low CSMR	22	112	0.2	15
High CSMR	129	8	16	15

Dump & fill 3 X /week  
 Low CSMR – Weeks 1-11  
 High CSMR – Weeks 12-24

75

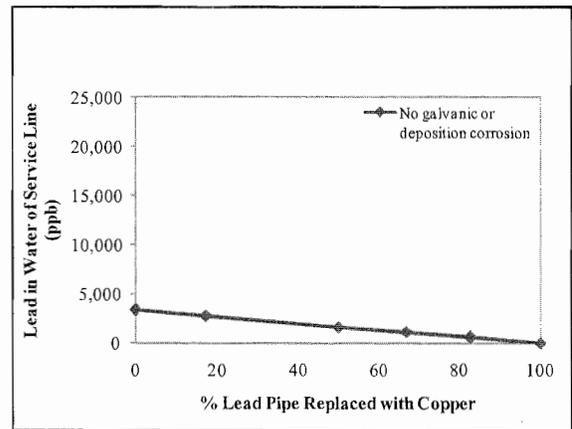


76

## Conclusions

- $\text{Cu}^{2+}$  in water increases Pb in water (deposition corrosion)
- Galvanic corrosion of Pb/Cu couples can be significant
  - Lower pH and higher Cl<sup>-</sup> at Pb junction during stagnation
  - Pb is sacrificed

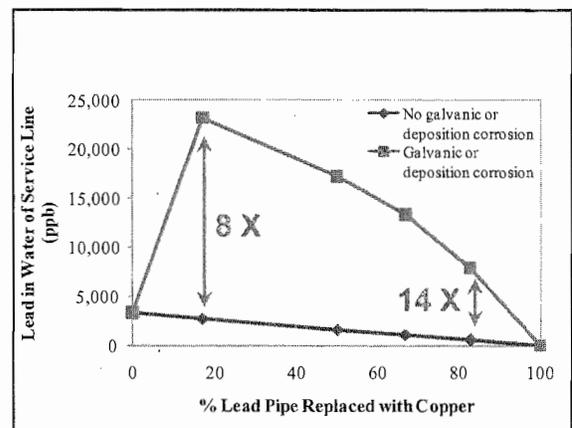
Virginia Tech  
The Power of Education



## Conclusions

- Simulated partial service line replacement
  - Higher Pb (>200%) in low CSMR water
  - Higher Pb (>165%) in high CSMR water
  - Short length of Cu relative to Pb had highest Pb release

Virginia Tech  
The Power of Education



## First Definitive Laboratory Data

indicating potential long-term detriments from galvanic and deposition corrosion arising from partial replacement.

Virginia Tech  
The Power of Education

## Acknowledgements

- EPA/Water Research Foundation (Project 4088)
- Traci Case
- PAC members
  - Chris Hill
  - France Lemieux
  - Joseph Marcinko
  - Anne Spiesman
- Edwards Research Group

Virginia Tech  
The Power of Education

**Impact of Chloride:Sulfate Mass Ratio (CSMR) Changes on Lead Leaching in Potable Water**

Jointly sponsored by:

US EPA/Water Research Foundation (Project #4088)

Caroline Nguyen, Simoni Triantafyllidou, Kendall Stone, Brandi Clark, and Marc Edwards

(Virginia Tech)

Graham Gagnon and Alisha Knowles

(Dalhousie University)

**Early Work on Galvanic Corrosion of Lead**

- "...solution of lead was assisted by contact with other metals" such as copper-lead connections (Wolffhugel, 1887)
- "...in practice, contact with iron pipes, solder, etc., is an important factor in assisting the attack on lead by water" (Lindsay, 1859)
- "...galvanic action is a most powerful agent in promoting the corrosive action of certain waters upon lead" (Stirling, 1859)
- "Occasionally the insertion of copper pipe can produce particularly bad results and despite satisfactory pH control it may be impossible to obtain satisfactory samples" (Britton and Richards, 1981)

**Previous Work on Chloride & Sulfate**

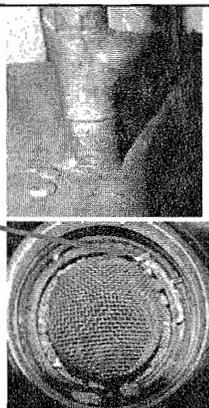
- Oliphant (1983) and Gregory (1985, 1986) linked lead contamination of waters to galvanic corrosion of lead solder
  - Found benefits from  $SO_4^{2-}$  and detriments from  $Cl^-$

**Previous Work**

- Dodrill & Edwards (1995): more lead with higher chloride and lower sulfate
- Pb poisonings in NC
  - Pb action level exceedance when coagulant changed from alum to PACl, shifting CSMR from low to high

"A 2-year old has been diagnosed with lead poisoning...They took the aerator off the sink [faucet] and tapped it in to the counter. It looked like asphalt pebbles, but it was solder"

*Raleigh News and Observer, 2005*



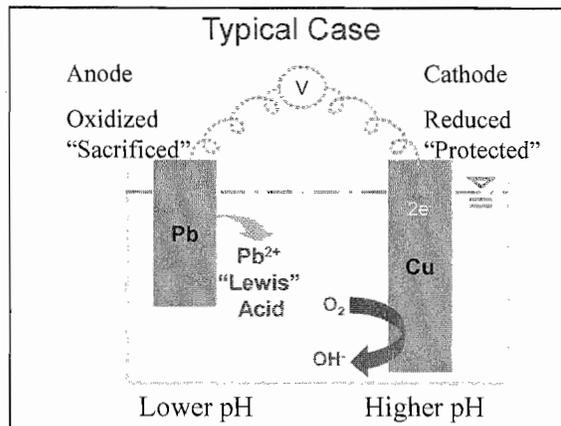
**Outline**

- Galvanic corrosion theory
- Mechanistic study
- How concerned should you be?
- Practical studies
  - Solder
  - Brass
  - Lead pipe

78

### Outline

- Galvanic corrosion theory
- Mechanistic study
- How concerned should you be?
- Practical studies:
  - Solder
  - Brass
  - Lead pipe

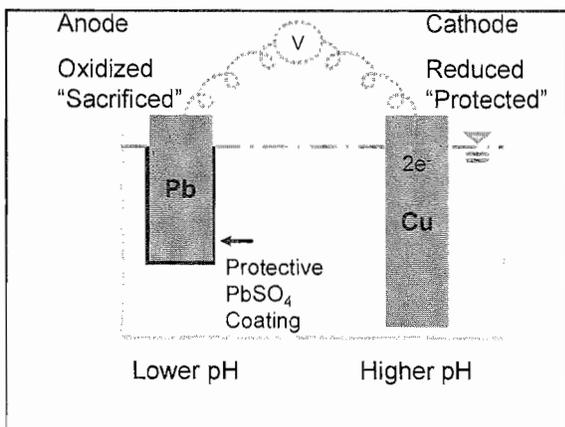
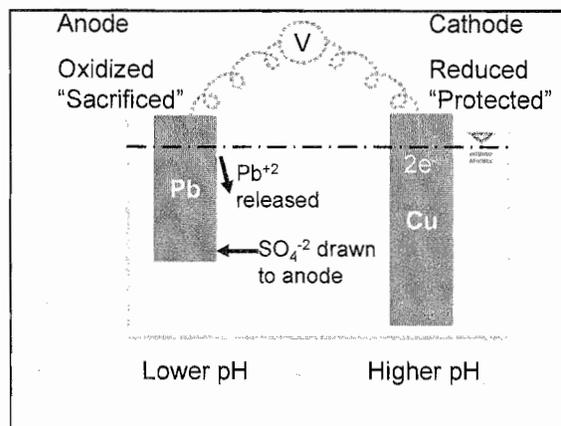


### Sulfate "Good"

- Sulfate precipitates lead at the anode

$$\text{Pb}^{2+} + \text{SO}_4^{2-} \rightarrow \text{PbSO}_4 \text{ solid}$$

Insoluble even at very low pH

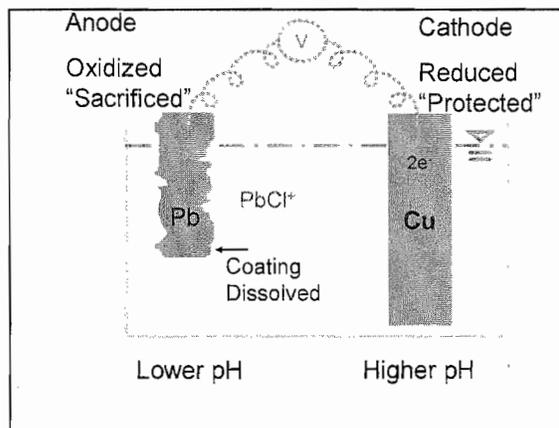
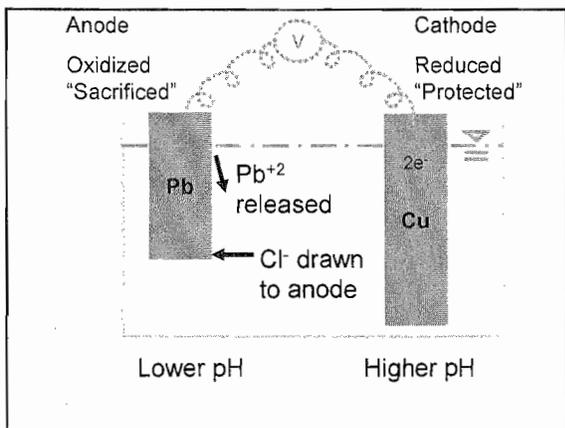


### Chloride "Bad"

- Chloride complexes lead

$$\text{Pb}^{2+} + \text{Cl}^- \rightarrow \text{PbCl}^+$$

- soluble
- prevents formation of solid



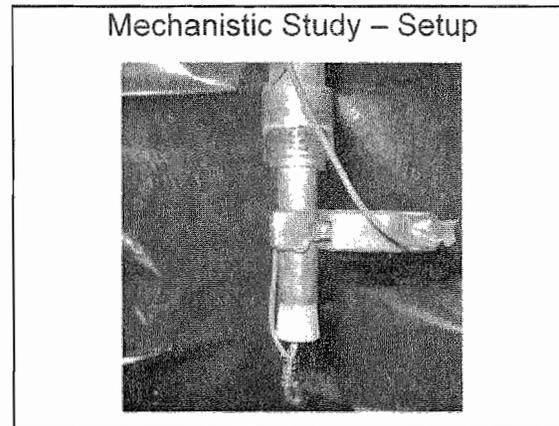
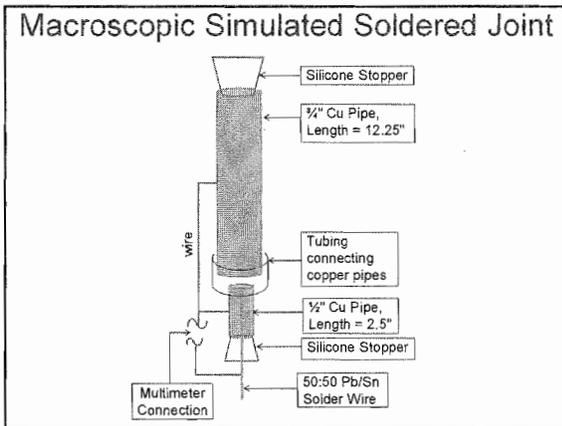
**Chloride to Sulfate Mass Ratio (CSMR)\*  
Sample Calculation**

Chloride to Sulfate Mass Ratio (CSMR) =  $\frac{\text{Bad}}{\text{Good}}$

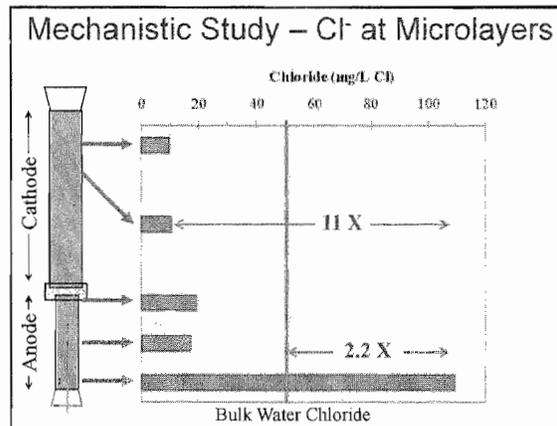
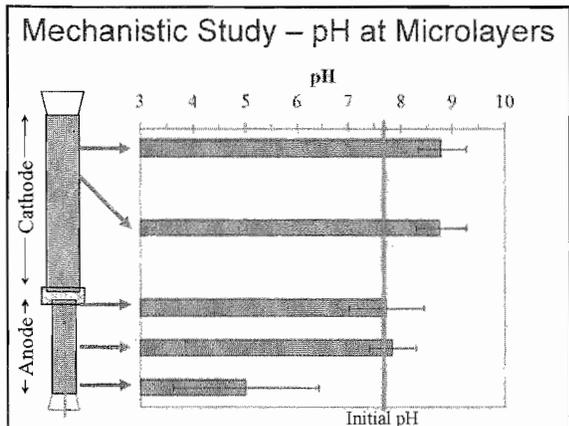
$$= \frac{[\text{Cl}^-]}{[\text{SO}_4^{2-}]} = \frac{10 \text{ mg/L Cl}^-}{20 \text{ mg/L SO}_4^{2-}} = 0.5$$

\* Oliphant, 1983; Gregory, 1985; Dodrill and Edwards, 1995

- Outline**
- Galvanic corrosion theory
  - **Mechanistic study**
  - How concerned should you be?
  - Practical studies:
    - Solder
    - Brass
    - Lead pipe



50

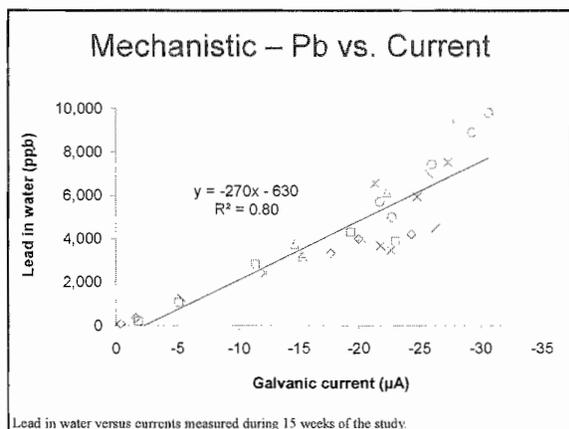


This provides 1<sup>st</sup> mechanistic explanation for why CSMR “works” in explaining trends in certain lead corrosion problems.

### Mechanistic Study - Water Quality (Utility I, MD)

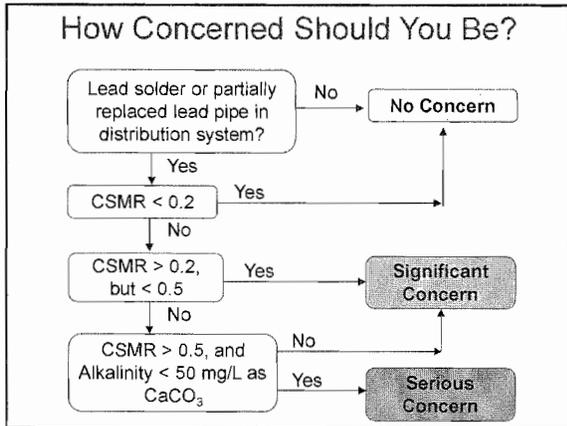
Water Conditions	CSMR
1) Alum-treated, free chlorine	1.4
2) Alum-treated, monochloramine	1.3
3) PACl-treated, free chlorine	5.3
4) PACl-treated, monochloramine	5.3
5) PACl-treated, +20 mg/L Cl <sub>2</sub> , free chlorine	8.5
6) PACl-treated, +20 mg/L Cl <sub>2</sub> , monochloramine	8.4

- pH 7.7 ± 0.1
- 3.5 mg/L Cl<sub>2</sub>
- 1 mg/L PO<sub>4</sub>-P



- ### Outline
- Galvanic corrosion theory
  - Mechanistic study
  - How concerned should you be?
  - Practical studies
    - Solder
    - Brass
    - Lead pipe

81



- ### Elevated CSMR from:
- Coagulants
    - Changing from sulfate-based coagulant to chloride-based coagulant
  - Hypochlorite generator brine leak
    - Switching from chlorine gas to hypochlorite on-site generator
  - Anion exchange
  - Use of desalinated water
  - Road salt runoff

- ### Outline
- Galvanic corrosion theory
  - Mechanistic study
  - How concerned should you be?
  - Practical studies:
    - Solder
      - Coagulants
      - Anion Exchange
      - Hypochlorite Brine Leak
      - Desalination
      - Illustrative Case Study
    - Brass
    - Lead pipe

### Simple Bench Scale Case Studies

- Simulated copper joints - 50:50 Pb:Sn solder placed inside copper coupling
  - 50:50 Pb:Sn solder - 1" length, 3 mm diameter
  - Cu coupling - 1" length, 1/2" diameter
  - Exposed to 100 mL of test water in triplicate

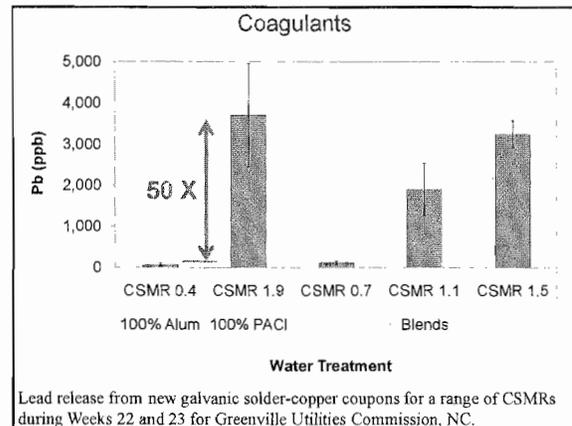
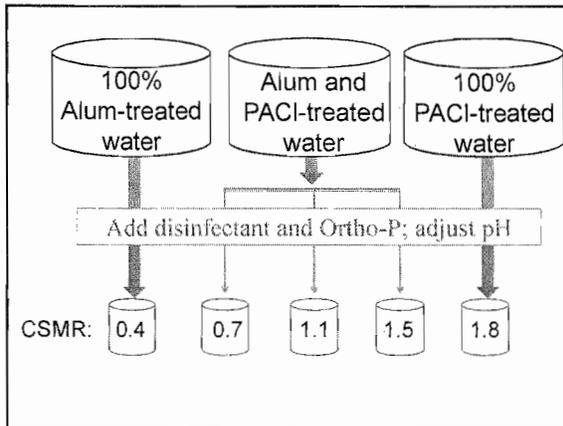


- ### Outline
- Galvanic corrosion theory
  - Mechanistic study
  - How concerned should you be?
  - Practical studies:
    - Solder
      - Coagulants
      - Anion Exchange
      - Hypochlorite Brine Leak
      - Desalination
      - Illustrative Case Study
    - Brass
    - Lead pipe

### Finished Water Chloride and Sulfate

Coagulant	Cl <sup>-</sup> (mg/L Cl)	SO <sub>4</sub> <sup>2-</sup> (mg/L SO <sub>4</sub> )	CSMR
100% Alum	16	40	0.4
Alum and PACl Blends	21	30	0.7
	22	24	1.1
	23	18	1.5
100% PACl	22	12	1.8
Raw Water	16	12	1.3

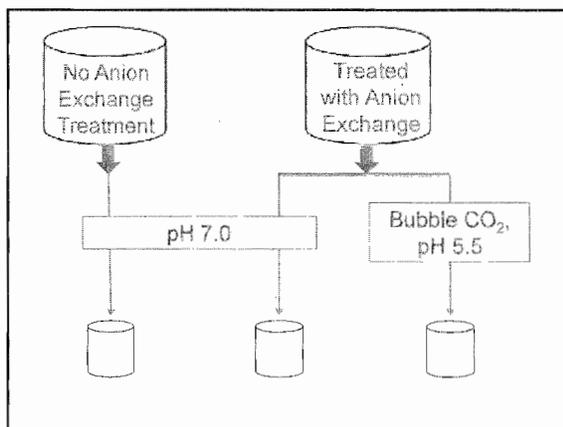
82



Lead release from new galvanic solder-copper coupons for a range of CSMRs during Weeks 22 and 23 for Greenville Utilities Commission, NC.

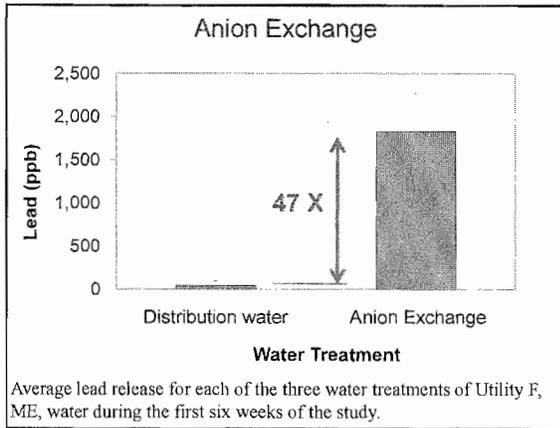
- ### Outline
- Valid and erosion theory
  - Mechanistic study
  - How concerned should you be?
  - Practical studies:
    - Solder
      - Coagulation
      - Anion Exchange
      - Hypochlorite brine leak
      - Desalination
      - Illustrative case study
    - Brass
    - Lead pipe

- ### Anion Exchange to Remove Arsenic
- Water naturally contained arsenic (As)
  - Anion Exchange used to remove As by replacing it with Cl<sup>-</sup> in water
  - SO<sub>4</sub><sup>2-</sup> also exchanged for Cl<sup>-</sup> → infinite CSMR
  - Following Anion Exchange, Pb in an apartment complex spiked >1,000 ppb
  - One child's BLL exceeded CDC BLL of concern (10 µg/dL) \*
- \* Edwards and Triantafyllidou, 2007

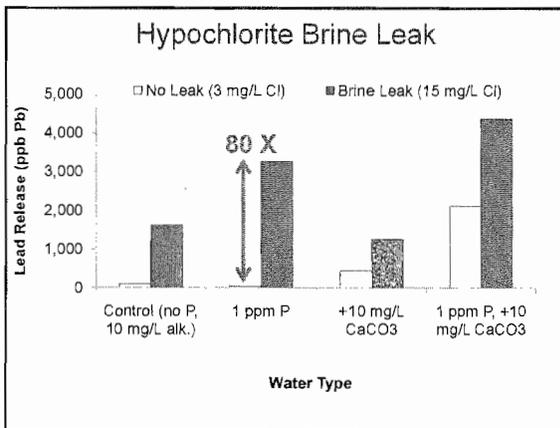


### Anion Exchange Treatment

Water Treatment	[As] µg/L As	[Cl] mg/L Cl	[SO <sub>4</sub> <sup>2-</sup> ] mg/L SO <sub>4</sub> <sup>2-</sup>	CSMR
Prior to Anion Exchange	4.5	4.4	4.1	1.1
After Anion Exchange	1.8	13.2	1.7	7.8



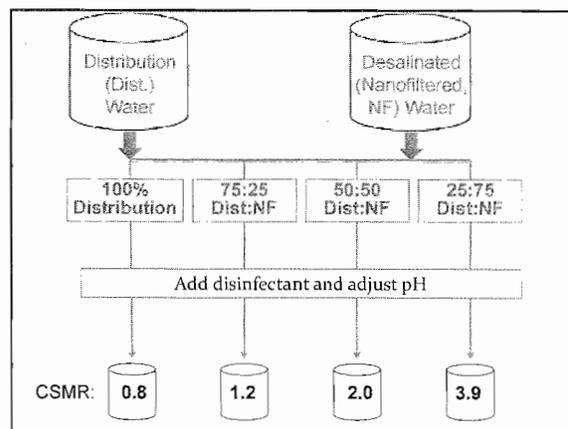
- ### Outline
- Galvanic corrosion theory
  - Mechanistic study
  - How concerned should you be?
  - **Practical studies:**
    - Solder
      - Coagulants
      - Anion exchange
    - **Hypochlorite Brine Leak**
      - Desalination
      - Illustrative case study
    - Brass
    - Lead pipe



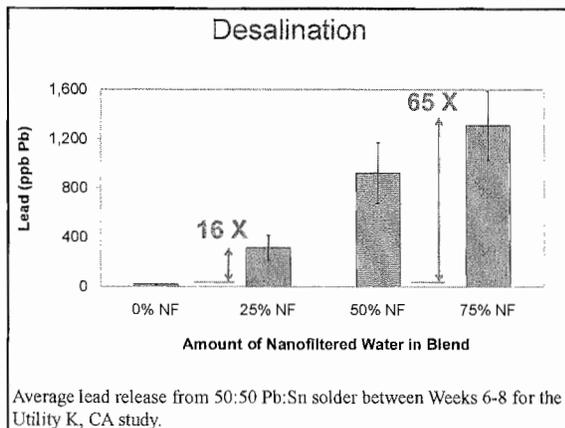
- ### Outline
- Galvanic corrosion theory
  - Mechanistic study
  - How concerned should you be?
  - **Practical studies:**
    - Solder
      - Coagulants
      - Anion exchange
      - Hypochlorite brine leak
    - **Desalination**
      - Illustrative case study
    - Brass
    - Lead pipe

**This utility plans to blend desalinated water with their current distribution water.**

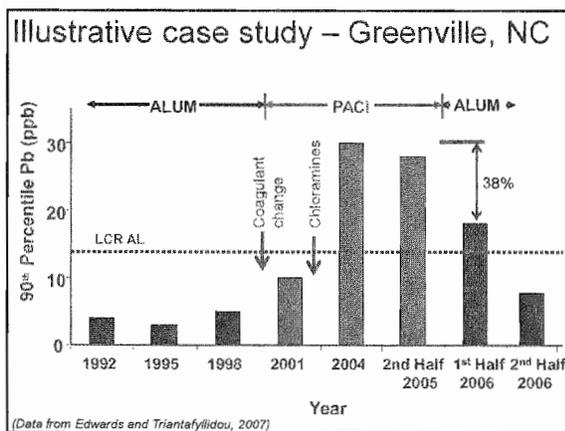
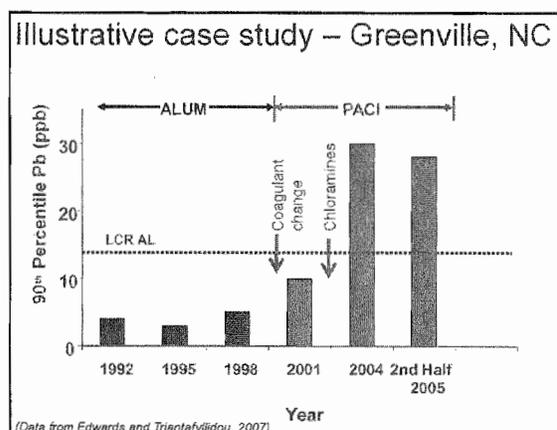
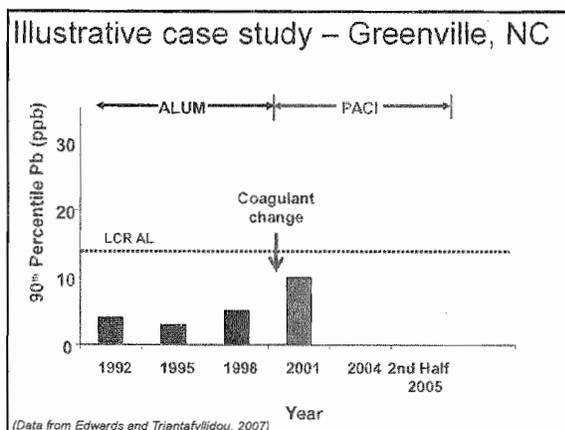
Blend	[Cl <sup>-</sup> ] mg/L	[SO <sub>4</sub> <sup>2-</sup> ] mg/L	CSMR
100% distribution	54	68	0.8
100% desalinated	110	Below detection	∞



54  
7



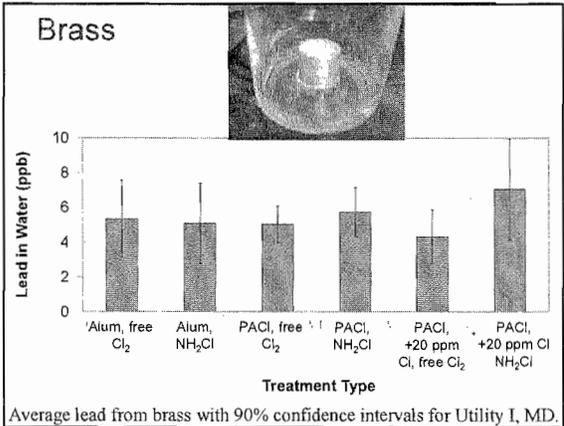
- ### Outline
- Galvanic corrosion theory
  - Mechanistic study
  - How concentrated should you be?
  - Practical studies:
    - Solder
      - Coagulants
      - Anion exchange
      - Hydrochloric acid leach
      - Desalination
    - Illustrative case study
      - Brass
      - Lead pipe



- ### Illustrative case study – Greenville, NC
- Chloramines had little effect
  - High CSMR had a major effect
  - Phosphate did not stop the problem
- Edwards and Triantafyllidou, 2007

### Outline

- Galvanic corrosion theory
- Mechanistic study
- How concerned should you be?
- Practical studies:
  - Solder
  - Brass
  - Lead pipe



### Conclusions (Solder)

- Simple bench scale test protocol
  - test treatment changes on lead leaching from solder-copper couplings
- Low pH measured at anode (pH 3.3)
- Anions (Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup>) migrate to the lead anode
- Lead sulfate is relatively insoluble, while chloride complexes lead and increases lead leaching
- Increased lead levels correlated with increased galvanic current
  - Galvanic effects are very persistent in some systems.

### Conclusions (Solder)

- Changes that increase CSMR can increase Pb release (and 90<sup>th</sup> percentile Pb)
  - Coagulants
  - Hypochlorite generator
  - Anion exchange
  - Desalination
  - Road salt runoff

**Effect limited to galvanic connections between Pb and Cu.**

### Conclusions (Solder)

- Effects of Alkalinity and Orthophosphate are site-specific
  - High orthophosphate or high alkalinity do not eliminate galvanic effects, but sometimes can reduce them.
  - Sometimes they make it worse

Because no universal solution exists, effects of inhibitors and treatment changes have to be evaluated on a site-specific basis using a simple protocol similar to that proposed here.

### Outline

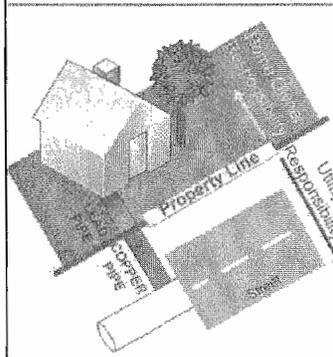
- Galvanic corrosion theory
- Mechanistic study
- How concerned should you be?
- Practical studies:
  - Solder
  - Brass
  - Lead pipe
- How big a problem is this?

*Handwritten initials/signature*

### Lead Service Lines

- “One of the most serious environmental disasters” in US history (Troesken, 2006)
- 3.3 - 6.4 million US homes with old lead service lines or connections, as of 1990 (Weston and EES, 1990)
- Contribute to an estimated 50 – 75 % of the lead in drinking water (Sandvig et al., 2008)
- Can contribute to violations of the 15 ppb LCR action limit for lead in drinking water

### Partial Lead Service Line Replacement (PLSLR)



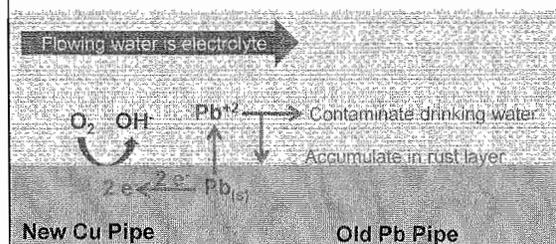
- **UK warning:** not recommended for lead level reduction, because “effects are unpredictable and may be contrary to those hoped for” (Chambers & Hitchmough, 1992)
- **US practice:** presumed to provide benefits over keeping the whole lead service line in place because “there will be a smaller volume of water in contact with the LSL” (US EPA, 2000)

### Potential Adverse Consequences of Partial Lead Service Line Replacements

- Disturbing rust scale and/or creating metallic lead particles when the lead pipe is cut (Boyd et al., 2004; Sandvig et al., 2008)
- Galvanic corrosion of lead (Britton and Richards, 1981)
- Deposition corrosion of lead (Britton and Richards, 1981)

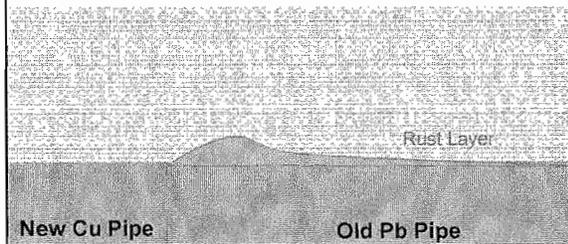
### Galvanic Corrosion

Can accelerate corrosion of the lead pipe, above and beyond what would normally occur for lead pipe alone



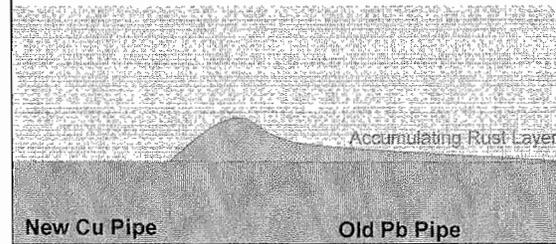
### Galvanic Corrosion

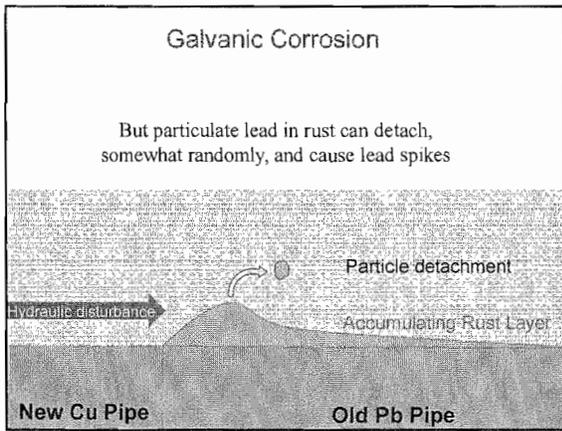
Lead that is galvanically corroded does not all go into the water.



### Galvanic Corrosion

Lead that is galvanically corroded does not all go into the water.

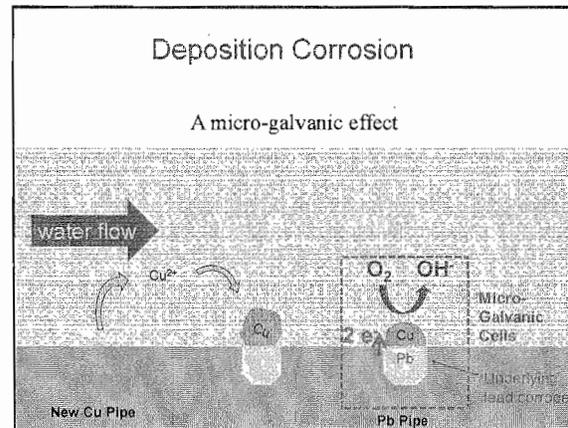
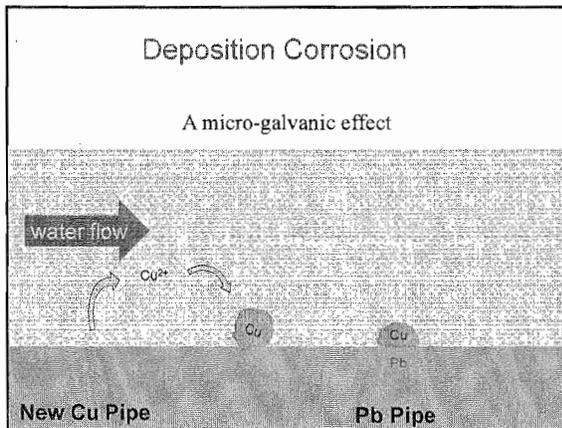




### Recent Work on Galvanic Corrosion

- "Partial replacements using copper piping can result in the creation of a galvanic cell, giving rise to increased and erratic levels of lead observed at the tap. The effect can be persistent and may well annul any beneficial effects of reducing the length of lead pipe in the system" (Chambers & Hitchmough, 1992)
- "<Edwards' group>...documented lead levels as high as 45,000 ppb by galvanically connecting an old lead pipe to one made of new copper under varying water conditions" (Renner, 2004)
- "The magnitude of galvanic impacts on aged and passivated LSL surfaces and on new copper surfaces is minimal, and in the long term, likely to be inconsequential" (Reiber and Dufresne, 2006)
- "Deep corrosion localized in the area immediately adjacent to the pipe joints suggests a galvanic mechanism" (DeSantis, Welch and Schock, 2009)

Definitive data are not available on the long-term implications relative to PLSLRs



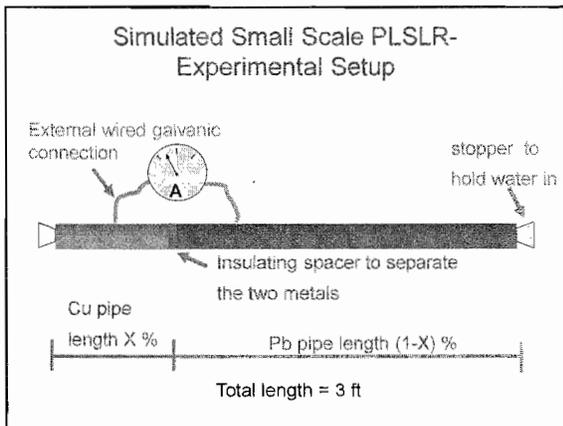
### Scenarios of Galvanic and Deposition Corrosion

Plumbing Type/ Sequence	Galvanic Junction(s)	Copper Deposition on Lead?
 Service House Pb      PVC	0	No
 Service House Pb      Cu	1	No
 Service after PLSLR House Cu      Pb      Cu Cu	2	Yes

Sequence is important

“Possible concern from inserting copper pipes or other apparatus upstream of and electrochemically linked to lead. Utilities should have clear advice/information systems so that such practices are avoided both by their own staff and by customers or tradesman.”

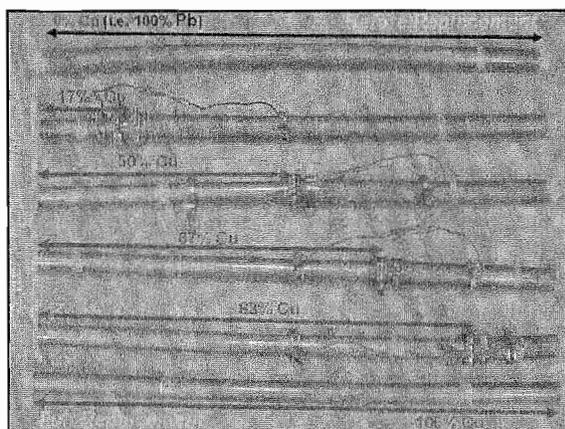
(Breach et al., 1991)



### Research questions

- Do Cu-Pb connections always passivate quickly in terms of galvanic current or lead leaching?
- Are effects of galvanic corrosion consequential in PLSLR?
  - Low CSMR water
  - High CSMR water

Evaluate worst case scenario of long stagnation



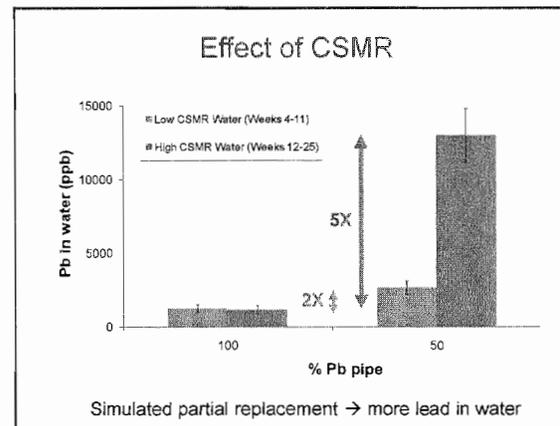
No cutting or other opportunity to mobilize scale from pipes

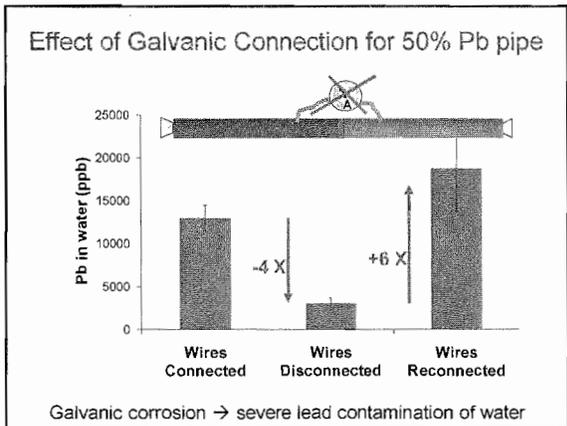
All effects attributable to galvanic/deposition corrosion alone

### Water Chemistry/Experimental Protocol

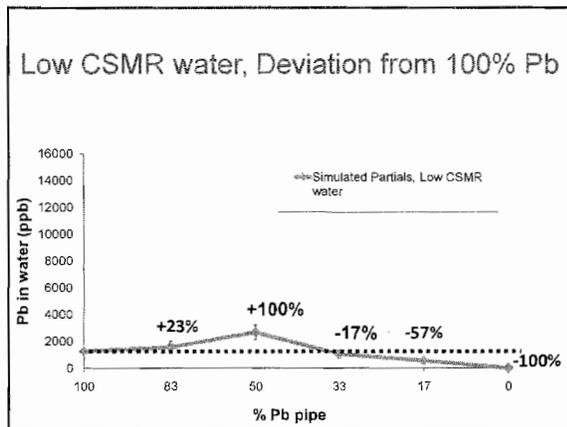
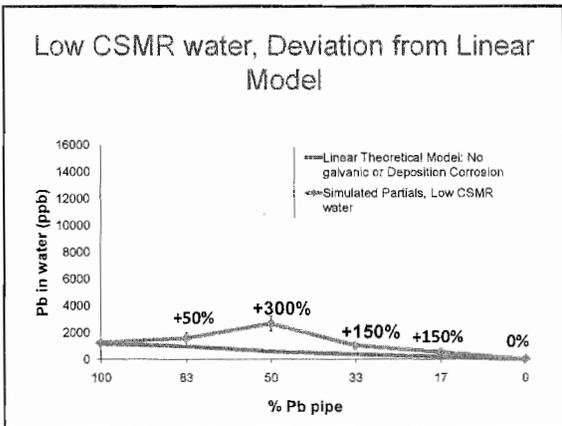
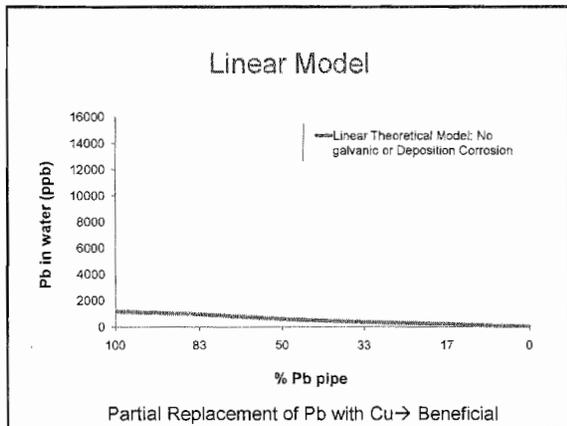
	Cl <sup>-</sup> (mg/L)	SO <sub>4</sub> <sup>2-</sup> (mg/L)	CSMR	Alkalinity (mg/L as CaCO <sub>3</sub> )	NH <sub>4</sub> Cl (mg/L as Cl <sub>2</sub> )	pH	Ionic Strength (mmol/L)
Low CSMR Water	22	112	6.2	15	4	8.0	4.6
High CSMR Water	129	8	16	15	4	8.0	4.4

Static "fill and dump" protocol:  
Water change 3 times/week



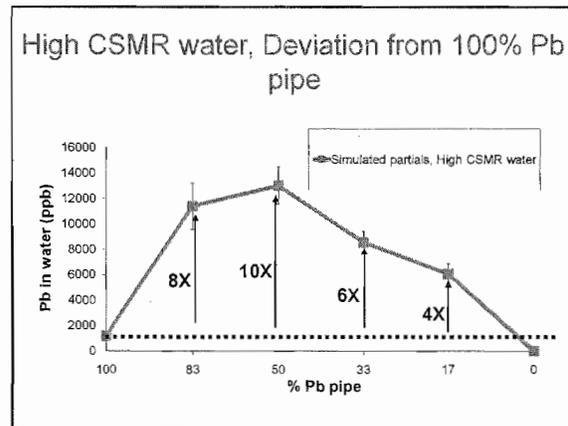
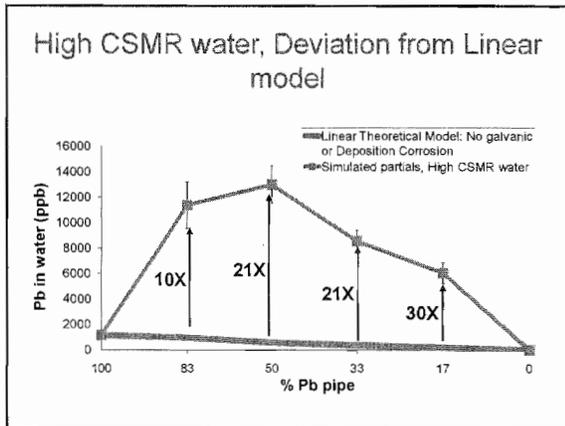


Laboratory study proves potential long-term detriments from galvanic and deposition corrosion arising from partial replacement

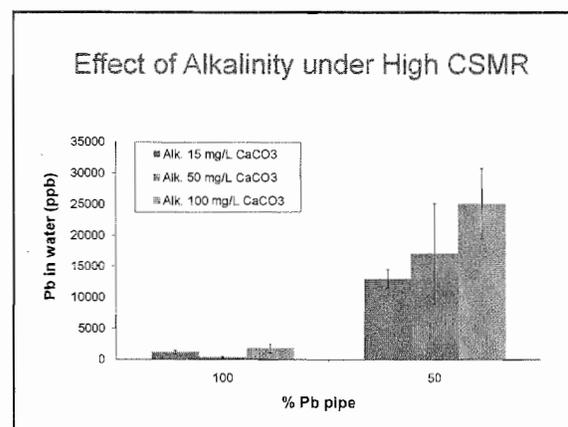
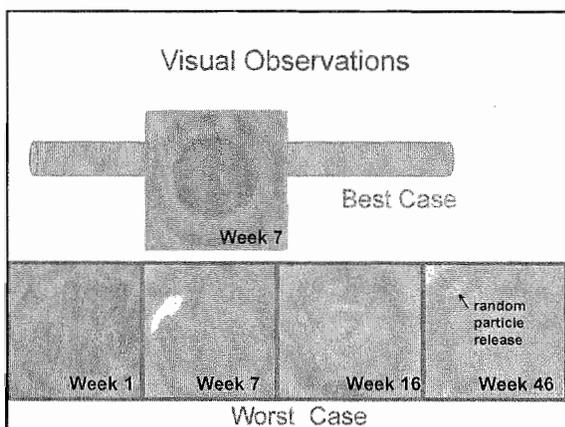
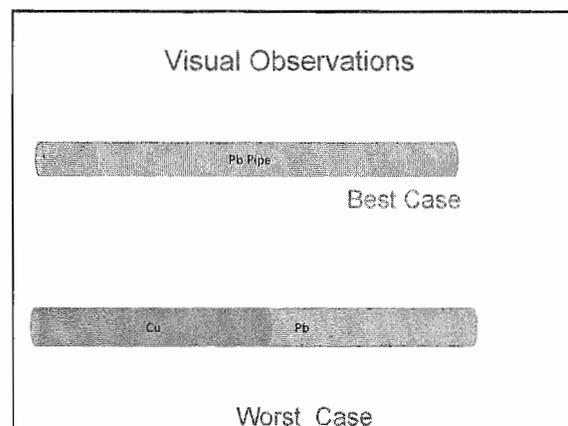


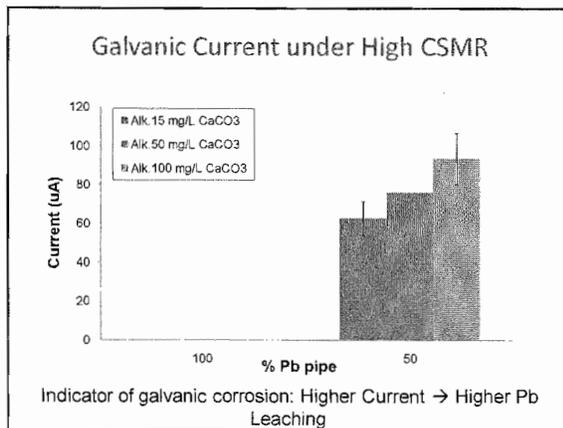
### Low CSMR water

- Even in low CSMR water, detriments of galvanic corrosion do counter benefits of reduced lead surface area
- Net benefit depends on magnitude of galvanic corrosion, % LSL replaced, and other factors



- ### High CSMR water
- Detriments of galvanic corrosion outweigh the benefits of reduced lead surface area, in every simulated partial replacement
  - Net benefit only when replacing 100% Pb pipe





### Conclusions from simulated PLSLR

Laboratory simulation of partial lead service line replacements under static "fill and dump" tests that lasted 1+ years showed:

- Galvanic corrosion significant both in Low CSMR and High CSMR water
- Increase of CSMR from 0.2 → 16 increased galvanic corrosion: Much more lead to the water and higher galvanic currents
- Increase of alkalinity from 15 → 50 → 100 mg/L as CaCO<sub>3</sub> did not reduce lead release or galvanic current magnitude, when the CSMR was high

### Conclusions from simulated PLSLR

Galvanic effect can be persistent.

We therefore confirm prior research that shows galvanic effect may "well annul any beneficial effects of reducing the length of lead pipe in the system"

### Future research questions on galvanic corrosion after simulated PLSLR

- Realistic flow patterns
- Effects of flow velocity (low versus high)
- Effects of protective film (harvested/passivated lead pipe versus new lead pipe)
- Effects of realistic couplings between lead and copper

### Outline

- Galvanic corrosion theory
- Mechanistic study
- How concerned should you be?
- Practical studies
  - Snide
  - Brass
  - Lead pipe
    - How big a problem is this?

How big a problem is this?

HDR-CADMUS-EPA REGION III Study (2006)\*

**“Can ...galvanic currents under a worst-case scenario meaningfully contribute to lead corrosion and metals release?”**

*The study provides a strong basis for discounting claims and concerns relative to accelerated metal release associated with PLSLR.*

\* [http://www.epa.gov/dclead/Gronding\\_Effects\\_Study\\_Final\\_November\\_2006.pdf](http://www.epa.gov/dclead/Gronding_Effects_Study_Final_November_2006.pdf)



**Important update: lead-based water lines \***

<The study of children in Washington DC>....suggest that when lead service lines are partially replaced.....children are more likely to have blood lead levels greater than or equal to 10 µg/dL..

\* (Frumkin, 2010)

**Explanations for disagreement**

HDR/Cadmus/EPA R3 conclusion

- is not based on the worst case
- did not measure lead release

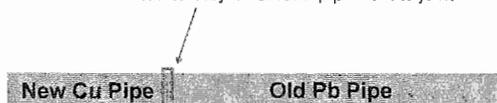
**Explanations (cont'd)**

For passivated lead pipe, galvanic impact is limited to only 1" of lead pipe next to joint, therefore, the galvanic effect is inconsequential



**Explanation #2**

For passivated lead pipe, galvanic impact limited to only 1" of lead pipe next to joint



Agree with the 1" part of the conclusion.

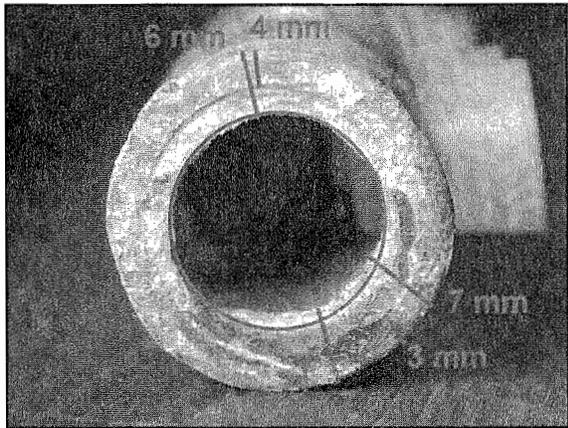
1" length of typical lead pipe half eaten away by galvanic corrosion  
= 24 g Pb

Sufficient to contaminate every drop of water consumed by a family of 4, over a more than a 10 year period, with lead concentrations above the 15 ppb AL.

It is sometimes even possible to see the effects of galvanic corrosion by eye.

**Mineralogical Evidence of Galvanic Corrosion in Domestic Drinking Water Pipes**  
 DeSantis, M., Welch, M. M., and Schock, M. R.  
 2009 WQTC

Obvious effects of galvanic corrosion sometimes apparent to naked eye



**Consider rate at which Pb is generated at galvanic connection**

Galvanic Current		Pb ( $\mu\text{g/day}$ )
1 $\mu\text{A}$	Very low rate	93
5 $\mu\text{A}$	Low rate	464
30 $\mu\text{A}$	High rate	2790
100 $\mu\text{A}$	Very high rate	9300

Bad News: "accessible lead greater than 175  $\mu\text{g}$  could result in elevated blood lead levels in children" CPSC (2005)

Good News?: Sometimes less than 1% of this lead is released to water, the rest goes into scale

There are many waters in which we are quite sure that Pb:Cu galvanic corrosion is not problematic at all.

**Conclusions**

The worst case can be quite bad.

When problems occur, they can be very hard to detect, due to erratic release of lead scale at joint. Sloughing of lead "rust" to a single sample could cause health concerns.

More research is needed to understand issues associated with sloughing of scale and galvanic corrosion.

## Acknowledgements

- Participating Water Utilities and Collaborators
  - Davidson Water (NC), City of Durham (NC), Greenville Utilities Commission (NC), Halifax Water (Nova Scotia), Jordan Valley Water Conservancy District (UT), Long Beach Water (CA), City of Minneapolis (MN), Portland Water Bureau (OR), City of Raleigh (NC), South Blount County Utility District (TN), Ville de Laval (Quebec), Washington Suburban Sanitary Commission (MD)
  - HDR: Glen Boyd, Anne Sandvig, and Al Vetrovs
- EPA/Water Research Foundation (Project 4088)
- Project Advisory Committee
  - France Lemieux, Chris Hill, Joseph Marcinko, Anne Spiesman, Traci Case (Project Manager)
- Edwards Research Group

## List of Presentations

- Nguyen, C.; Edwards, M.; Stone, K.; Clark, B. Mechanistic Effects of Chloride-to-Sulfate Ratio on Lead Corrosion. 2008 AWWA Annual Conference, Atlanta, GA. Presentation TUE16. June 2008.
- Stone, K.; Nguyen, C.; Edwards, M.; Clark, B. Effects of Coagulant and Other Treatment Changes on Lead Leaching. 2008 AWWA Water Quality Technology Conference. Cincinnati, OH. November 2008.
- Stone, K.; Nguyen, C.; Edwards, M. Practical Identification and Resolution of Lead Corrosion Issues Due to Elevated Chloride-to-Sulfate Mass Ratio. 2009 AWWA Annual Conference. San Diego, CA. Presentation WED32-2:30. June 2009.
- Clark, B.; Nguyen, C.; Edwards, M. Effects of Alkalinity on Galvanic Corrosion of Lead Solder in Low Conductivity Waters. 2009 AWWA Annual Conference. San Diego, CA. Presentation WED32-3:30. June 2009.
- Nguyen, C.; Triantafyllidou, S.; Hu, J.; Edwards, M. The Effect of Partial Lead Service Line Replacements on Lead Leaching. 2009 AWWA Annual Conference. San Diego, CA. Presentation TUE30-3:00. June 2009.
- Triantafyllidou, S.; Nguyen, C.; Edwards, M. Contribution of Galvanic Corrosion to Lead in Water after Partial Lead Service Line Replacements. 2009 AWWA Water Quality Technology Conference. Seattle, WA. Presentation WED7. November 2009.

## References

- Boyd, G., Shetty, P.; Sandvig, A., and G. Pierson., 2004. Pb in tap water following simulated partial lead pipe replacements. *Jour. Environ. Engrg.*, 130(10):1188-1197.
- Breach R.A. et al., 1991. A systematic approach to minimizing lead levels at consumers taps. In proceedings of AWWA1991 Annual conference, Philadelphia, PA.
- Britton, A., and Richards, W., 1981. Factors influencing Plumbosolvency in Scotland. *Journal of the Institution of Water Engineers and Scientists*, 35(4):349.
- Chambers V.K. and Hitchmough S.M., 1992. Economics of lead pipe replacement (TMU. 6030). Final report to the Department of the Environment, DOE 2956/1.
- DeSantis, M., Welch, M. M., and Schock, M. R., 2009. Mineralogical Evidence of Galvanic Corrosion in Domestic Drinking Water Pipes. Proceedings of the AWWA WQTC conference, Seattle, Washington.
- Dodrill, D.M., and Edwards, M., 1995. Corrosion Control on the Basis of Utility Experience. *Jour. AWWA*, 87(7):74.
- Dudi, A., 2004. Reconsidering Lead Corrosion in Drinking Water: Product Testing, Direct Chloramines Attack and Galvanic Corrosion. M.S. Thesis, Virginia Tech, Blacksburg, VA.
- Edwards, M., and Triantafyllidou, S., 2007. Chloride-to-sulfate mass ratio and lead leaching to water. *Jour. AWWA*, 99(7):96.
- Frumkin, H., 2010. Important update: lead-based water lines. Accessed at <http://www.cdc.gov/health/effects/water/lines.htm>
- Gregory, R., 1985. Galvanic Corrosion of Lead in Copper Pipework: Phase I, Measurement of Galvanic Corrosion Potential in Selected Waters. Water Research Center Engineering.
- Gregory, R., 1985. Galvanic Corrosion of Lead in Copper Pipework: Phase II, Effects of Treatment on Galvanic Corrosion Potentials. Water Research Center Engineering.
- Gregory, R., 1986. Galvanic Corrosion of Lead in Copper Pipework: Phase III, Methods of Dosing Zinc to Inhibit Corrosion. Water Research Center Engineering.

## References

- Gregory, R., 1990. Galvanic Corrosion of Lead Solder in Copper Pipework. *Water and Environment Journal*, 4(2):112.
- Ingleson, H., 1934. The action of water on lead with special reference to the supply of drinking water. Harrison and Sons: London.
- Lindsay, W.L., 1859. On the Action of Hard Waters upon Lead. *Edin. New Phil. Journal*, (9):245 and (10):8.
- Oldfield J.W., 1996. Electrochemical Theory of Galvanic Corrosion. In "Galvanic Corrosion" - ASTM STP 979 - H.P. Hack Ed., ASTM International, West Conshohocken (PA).
- Oliphant, R.J. (1963) Summary Report on the Contamination of Potable Water by Lead from Soldered Joints. Water Research Center Engineering, Swindon, External Report 125-E.
- Reiber, S., and Dufresne, 2006. Effects of External Currents and Dissimilar metal contact on Corrosion of Lead from Lead Service Lines. Final Report to USEPA region III.
- Renner, R., 2004. Plumbing the Depths of D.C.'s Drinking Water Crisis. *Environ. Sci. Technol.*, 38 (12): 224A-227A.
- Tang, Z.; Hong, S.; Xiao, W.; Taylor, J., 2006. Impacts of blending ground, surface, and saline waters on lead release in drinking water distribution systems. *Water Research*, 40(5):943.
- Taylor, J., Dietz, J.; Randall, A.; Hong, S., 2004. Impact of RO-desalted water on distribution water qualities. *Water Science and Technology*, 51(6-7):285.
- Troesken, W., 2006. The Great Lead Water Pipe Disaster. Cambridge, MA: MIT Press.
- US EPA, 2000. Federal Register /Vol. 65, No. 8, p. 1965.
- Weston and EES, 1990. Lead Service Line Replacement: A benefit to cost analysis. American Water Works Association, Denver, CO.
- Wolffhugel, G., 1887. Water Supply and Lead Poisoning. Views on the Poisoning Cases which Occurred in Dessau in 1886. *Arb. Gesundheitsamt, Berlin*, (2) 484.

## Contact Information

- Marc Edwards  
Email: [edwardsm@vt.edu](mailto:edwardsm@vt.edu)
- Caroline Nguyen  
Email: [cknguyen@vt.edu](mailto:cknguyen@vt.edu)
- Simoni Triantafyllidou  
Email: [striant@vt.edu](mailto:striant@vt.edu)

# Effect of flow rate and lead/copper pipe sequence and junction types on galvanic & deposition corrosion of lead pipe

Cartier, Clément<sup>1</sup>; Nour, Shokoufeh<sup>1</sup>; Laurent Laroche<sup>2</sup>; Marc Edwards<sup>3</sup>; Prévost, Michèle<sup>1</sup>

<sup>1</sup> NSERC Industrial Chair in Drinking Water, Civil, Geological and Mining Engineering Department, Ecole Polytechnique, Montreal, Qc  
<sup>2</sup> City of Montreal, Technical Expertise Division, Charles-J. DesBaillets Laboratory, Montreal (Qc)  
<sup>3</sup> Virginia Polytechnic Institute & State University, Jr. Department of Civil and Environmental Engineering, Blacksburg, Virginia, USA



clement.cartier@polymtl.ca

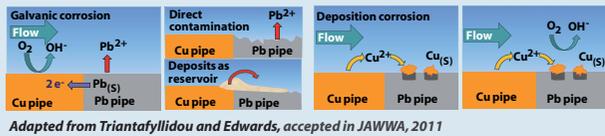


CANADIAN WATER NETWORK  
 RÉSEAU CANADIEN DE L'EAU

### Introduction

Water utilities have been spending billions on partial lead service line replacements with copper. However, limited data is available on its effectiveness.

Recent pipe rig research conducted at Virginia Tech suggested that lead release can be exacerbated by galvanic corrosion attributable to the contact between copper and lead. Deposition corrosion was also suspected.



### Objectives

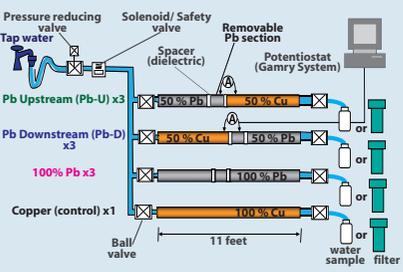
- Phase 1**
- Study short and long-term galvanic impacts on partial lead service line replacement
  - Evaluate the effect of flow rate on galvanic corrosion
- Phase 2**
- Assess the effect of junctions/ release from material versus lead release from galvanic (ongoing experiments)
- Phase 3**
- Determine the impact of long term galvanic corrosion following partial service line replacement on lead release using:
    - Excavated lead pipe stabilized over 1 year
    - Typical configurations, junctions, and flow rates
    - 4 water conditions including corrosion inhibitors

### Acknowledgment

- CWN & NSERC
- The City of Montreal (supports, lead pipes, lead analyses)
- Yves Fontaine (pipe loop assembly and operation)
- Généviève Senécal-Léonard and Stéphanie Fay (interns)
- Roger Arnold, Simoni Triantafyllidou et Jeff Parks (VT)

## Phase 1: Effect of pipe sequence and flow rate

### Experimental protocol (conducted at Virginia Tech.)



- 2 Flow events every day 8 hours apart
  - Low flow rate of 1.3 LPM for 100 minutes
  - 16 hr overnight stagnation
- Conditions preventing important Pb release
- Non aggressive water
  - Low flow promotes scale formation and reduce galvanic effect
  - New Pipe: No pipe cutting or particulate lead mobilization

Water parameters:

pH	7.4
Alkalinity (mg CaCO <sub>3</sub> /L)	31
Disinfection: chloramines (Tot Cl <sub>2</sub> mg/L)	2.6
Orthophosphate (mg P/L)	0.5
Cl <sup>-</sup> (mg/L)	15.4
SO <sub>4</sub> <sup>2-</sup> (mg/L)	6.2
Temp (°C)	20

Sampling:

Low flow: 3 times/week (up to July) then 2 times/month  
 Med flow: 2 times/month  
 High flow: Once/month (except December)

## Phase 2: Effect of junctions type

### Experimental protocol

Conducted at Polytechnique in collaboration with Virginia Tech. (ongoing experiments)

- Pipe rigs to assess the effect of junction on galvanic corrosion - 0.4 L/rig
- Cumulative sampling 3 x / week with an average 56 hrs stagnation time



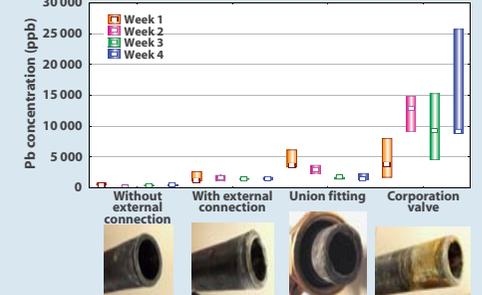
Water parameters:

pH	8.5
Alkalinity (mg CaCO <sub>3</sub> /L)	118
Free chlorine (Cl <sub>2</sub> mg/L)	0.00
Cl <sup>-</sup> (mg/L)	22
SO <sub>4</sub> <sup>2-</sup> (mg/L)	28
Temp (°C)	20

### Junctions tested

Junction Type	Appearance	Nb Replicate	Distance Pb vs Cu
Spacer without external connection		3 X	0.1"
Spacer with wire external connection		3 X	0.1"
Union fitting (brass)		3 X	≈0"
Corporation valve (brass)		3 X	≈2.0"

### Results - after one month



For Spacer with external wire connection  
 Current: before stagnation: 46 µA and after stagnation: 30 µA

### Preliminary conclusions

- Higher lead release was observed under galvanic corrosion conditions
- Corporation valves (as used usually on the field) are the worst case after four weeks (and going worst) possibly due to crevice corrosion
- After four weeks, union fittings and spacer with external connection produce similar results
- Upcoming experiments: Investigate lead release specific to the fittings

## Phase 3: Pilot experiment

### All conditions tested simultaneously under different water quality

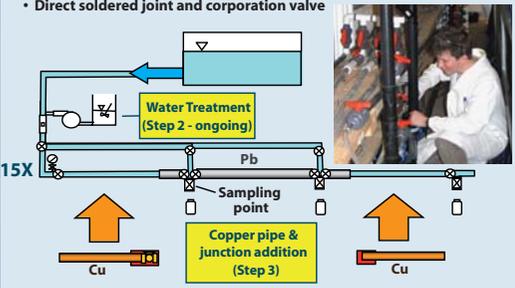
#### Experimental protocol

Conducted at Polytechnique (ongoing experiments)

- Step 1: 1 year stabilization**
- 5 LPM during 8 hrs (16 hrs stagnation)
  - 5 stages x 3 pipes / stage x 3 section (60 cm + 300 cm + 60 cm) / pipe = 45 Pb sections
- Step 2: Treatments (ongoing)**
- Stage 1: sulfate addition to prevent galvanic corrosion
  - Stage 2: orthophosphates addition as corrosion inhibitor (2 mg P/L then 1 mg P/L)
  - Stage 3: control
  - Stage 4: pH from 7.8 to 8.3
  - Stage 5: sampling under high flow (15 LPM)
- Step 3: Copper pipe & junction addition (planned)**
- Direct soldered joint and corporation valve

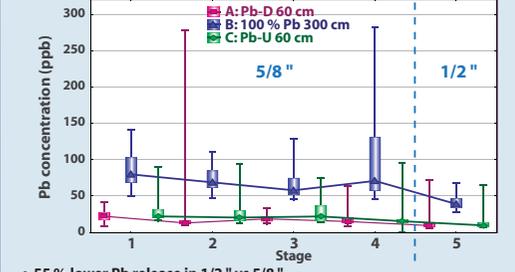
Water parameters:

pH	7.8
Alkalinity (mg CaCO <sub>3</sub> /L)	82
TOC (mg/L)	3.0
Free chlorine (Cl <sub>2</sub> mg/L)	0.06
Cl <sup>-</sup> (mg/L)	22
SO <sub>4</sub> <sup>2-</sup> (mg/L)	28
Temp (°C)	16



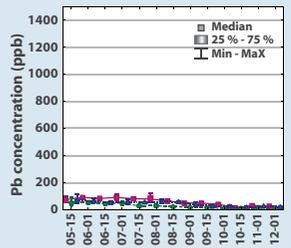
### Results

After 1 year of stabilization & 8 weeks of sampling before treatment without Cu junctions



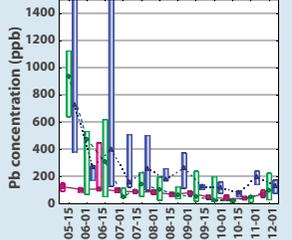
- 55% lower Pb release in 1/2" vs 5/8"
- Significantly lower lead release from the 60 cm vs 300 cm (25 ppb vs 76 ppb)
- Under flow, lead concentration in 300 cm section (N = 10): < 10 ppb (mean = 5.6 ppb)

### Low flow (1.3 LPM)

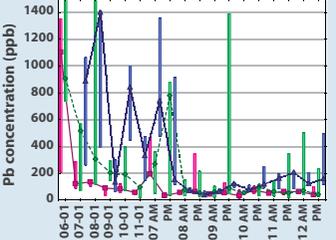


### Results - after one month

#### Medium flow (8 LPM)



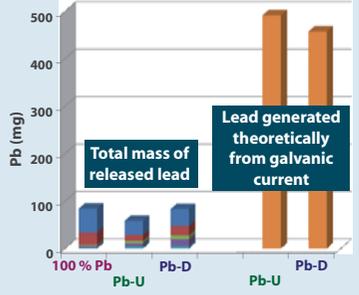
#### High flow (32 LPM)



### Conclusions

- Under low flow:**
- Short-term lead "spike" was observed for few weeks after partial replacement due to galvanic effect comparing to full lead pipe. During 3 following months, as scale became accumulated at the junction, the partial pipes released less lead than the 100% Pb pipe.
  - For 50% Pb-D pipe, lead release was never proportional to the length of lead pipe comparing to 100% Pb pipe
  - At the end of the experiment, lead release from Pb-D and 100% Pb were comparable.
- Under medium/High flow:**
- Even if lead release was decreasing with time, lead release was exacerbated by the flow events for Pb-D and Pb-U conditions
  - Under high flow, lead release was significant for Pb-U and Pb-D conditions even if the samples were taken at a higher frequency which confirms the presence of mobilized lead scales
- In terms of mass balance:**
- For 50% lead pipe upstream of copper pipe (Pb-U), lead release is slightly higher than expected based on lead pipe length which confirms the galvanic effect
  - The difference between Pb-D and Pb-U can be explained by deposition corrosion
  - At Longer-term, under low flow, the slight benefit of partial pipe replacement disappears, and may even be reversed eventually, due to release of lead scale accumulated at joint from galvanic connection.
  - Considering relatively stable high current (not presented here), this situation persist indefinitely

### Cumulative mass balance



- Pb from current (mg)
- Ext. Samp.
- 32 LPM
- 8 LPM
- 1.3LPM - First draw
- 1.3 LPM flow

1 The following is a draft version of a paper submitted to *Critical Reviews in Environmental Science and*  
2 *Technology*, and which was accepted for publication in that journal after minor revisions to this draft (this  
3 version is unrevised). The title for the published version has been changed to **Lead (Pb) in Tap Water**  
4 **and in Blood: Implications for Lead Exposure in the United States**  
5  
6

## 7 **Lead (Pb) in Tap Water and in Blood: A Critical Review**

8  
9 Simoni Triantafyllidou, Marc Edwards  
10 Department of Civil and Environmental Engineering, Virginia Tech, Durham 418,  
11 Blacksburg, VA  
12  
13

### 14 **ABSTRACT**

15  
16 *Lead is widely recognized as one of the most pervasive environmental health threats in*  
17 *the United States (US), and there is increased concern over adverse health impacts at*  
18 *levels of exposure once considered safe. Lead contamination of tap water was once a*  
19 *major cause of lead exposure in the US and, as other sources have been addressed, the*  
20 *relative contribution of lead in water to lead in blood is expected to become increasingly*  
21 *important. Moreover, prior research suggests that lead in water may be more important*  
22 *as a source than is currently believed. This review describes sources of lead in tap*  
23 *water, chemical forms of the lead, and relevant US regulations/guidelines, while*  
24 *considering their implications for human exposure. Research that examined associations*  
25 *between water lead levels and blood lead levels is critically reviewed, and some of the*  
26 *challenges in making such associations, even if lead in water is the dominant source of*  
27 *lead in blood, are highlighted. Better protecting populations at risk from this and from*  
28 *other lead sources is necessary, if the US is to achieve its goal of eliminating elevated*  
29 *blood lead levels in children by 2020.*  
30

31  
32 **KEY WORDS:** plumbing, tap water, dissolved lead, particulate lead, regulations, health  
33 effects, blood lead level, correlation  
34  
35  
36  
37  
38  
39

---

40 Portions of sections VI and VII were presented at the Yale University Drinking Water  
41 Symposium in April 2009 and appeared as a supplemental paper of that symposium.  
42

43 Address correspondence to Marc Edwards, Department of Civil and Environmental  
44 Engineering, Virginia Tech, Durham 418, Blacksburg, VA 24061, USA. E-mail:  
45 edwardsm@vt.edu

4  
129

## I. INTRODUCTION

Lead (Pb) is widely recognized as one of the most pervasive environmental health threats in the United States (US). Dramatic progress has been made over the last four decades to reduce lead exposure from gasoline, paint, dust, food/drink cans and drinking water (Shannon, 1996). However, despite reduced exposure from nearly all sources, clinical evidence has demonstrated adverse health impacts at blood lead levels once considered safe (Fadrowski et al., 2010; Jusko et al., 2008; Bellinger and Needleman, 2003). As a result, while the incidence of elevated blood lead (EBL) has markedly decreased, public sensitivity and medical concern about even low level lead exposure has increased. In order for the US to achieve its goal of eliminating all instances of EBL in children by 2020 (US Department of Health and Human Services, 2010), improved understanding of exposure to all lead sources is necessary.

Defining a "typical" case for childhood lead exposure can be mis-leading, because lead exposure affects individuals whose behavior and environments are infinitely variable. Nonetheless, it is often stated that in the typical case, drinking water consumption is believed to account for up to 20% of total lead exposure nationally (US EPA, 2006). But the US EPA also acknowledged that for infants consuming formula it may account for more than 50% of their total lead exposure, and further predicted that the relative importance of lead in water as a source would increase as other lead sources were being addressed (US EPA, 1991). Recent work has demonstrated that in exceptional cases, lead from water can be the dominant source of exposure in children with EBL. For example, isolated cases of childhood lead poisoning in North Carolina and in Maine were tied to drinking water (Triantafyllidou et al., 2007). In addition, a 2009 study linked the incidence of EBL in Washington DC during a period of very high lead-in-water contamination, with effects of water much more significant for the youngest children tested (Edwards et al., 2009). Finally, the Centers for Disease Control and Prevention (CDC) publicized preliminary results of an epidemiological study, which demonstrated associations between children's EBL and partially replaced lead water pipes (Frumkin, 2010).

The goal of this work is to conduct a critical review of the literature, with emphasis on:

- The release of hazardous levels of lead in tap water from old lead-bearing plumbing materials
- Lead contamination of tap water as a public health concern even in modern buildings, and in cities that might meet federal regulations for lead in tap water
- The absence of federal regulations for lead in drinking water of US schools and day care facilities
- The difference between dissolved and particulate lead release into tap water, and the challenges in monitoring and exposure assessment associated with the particulate lead fraction
- Some of the challenges in associating Water Lead Levels (WLLs) to Blood Lead Levels (BLLs) in population studies or in case studies
- Important aspects of population studies that did, or did not, find associations between lead in water and lead in blood.

1       **II. SOURCES OF LEAD IN TAP WATER, HOUSEHOLDS AT POTENTIAL**  
2                   **RISK, AND POTENTIAL IMPORTANCE COMPARED TO OTHER**  
3                   **ENVIRONMENTAL LEAD SOURCES**  
4

5       **Sources of Lead in Tap Water.** Drinking water usually contains little or no lead when it  
6 leaves the water treatment plant and as it travels through water mains (Figure 1). But as  
7 it enters building plumbing through service line connections, it may come into contact  
8 with lead-containing plumbing materials (Figure 1). These materials include lead pipe,  
9 lead-containing solder used to join copper and other metallic pipes together, and  
10 plumbing devices made of lead-containing brass (e.g., water meters, valves, components  
11 in water fountains and in faucets) (Figure 1). As water flows through or sits stagnant in  
12 the pipes and in other plumbing devices, it can become contaminated with lead through a  
13 variety of complex electrochemical, geochemical and hydraulic mechanisms (Schock et  
14 al., 1996). Lead that is released from the plumbing can contaminate water at the tap in  
15 one of two forms: as particulate lead or as dissolved lead (Figure 1).  
16

17       **Lead pipe.** Lead pipe was used for the conveyance of drinking water, because it is easily  
18 formed, cut and jointed, and because its flexibility provides resistance to subsidence and  
19 frost (Schock et al., 1996). An advertisement by the National Lead Company in 1923  
20 (National Geographic, 1923) illustrated that in many cities the law required that “lead  
21 pipe alone be used to bring water from street mains into the building” (Figure 2). Use of  
22 lead pipe in service lines was standard practice in many US cities through the 1950’s, and  
23 despite well-known health concerns was even occasional practice until the Congressional  
24 ban effective 1986. Considering health impacts from drinking water contamination, one  
25 historian characterized use of lead pipes in major cities as “one of the most serious  
26 environmental disasters” in US history (Troesken, 2006). Even though the use of lead  
27 pipe in service lines or premise plumbing was prohibited in the US by the Safe Drinking  
28 Water Act (SDWA) of 1986 (US EPA, 2006), older buildings may still be connected to  
29 lead service lines, lead goosenecks and other pure lead components. Depending on their  
30 length and diameter, water corrosivity, water use patterns as well as hydraulic patterns,  
31 lead service lines generally account for 50-75% of lead contamination at the tap in older  
32 homes where they are present (Sandvig et al., 2008).  
33

34       **Partially Replaced Lead Pipe.** In the US, ownership of the lead pipe in service lines is  
35 shared between water utilities and homeowners. The controversial and expensive  
36 practice of replacing the utility’s portion of an old lead service line with copper, while  
37 leaving behind the customer’s portion, has been conducted in many cities with the  
38 purported goal of reducing lead in drinking water at the tap. Such replacements are  
39 termed “partial lead pipe replacements.” This practice can actually increase water lead  
40 concentrations at least in the short-term (days to weeks), and for an undetermined  
41 duration beyond that time (Sandvig et al., 2008). The short-term effect is due to  
42 disturbance of the lead rust (i.e., corrosion scale) that has accumulated on the lead pipe  
43 over decades/centuries of use, and/or from creation of metallic lead particles when the  
44 lead pipe is cut. Recent research has also shown that in some situations, the creation of a  
45 galvanic cell (i.e., battery) between the lead pipe and the copper pipe may create serious  
46 water lead contamination in both the short-term and longer-term (Triantafyllidou et al.,

1 2009a), confirming long-held concerns (Chambers and Hitchmough, 1992). This might  
2 explain the higher incidence of EBL in children living in homes with partially replaced  
3 lead pipe, when compared to homes with full lead pipes (Frumkin, 2010).

4  
5 **Lead solder.** Solder is melted to join metallic plumbing materials together in a strong  
6 and water-tight seal (Figure 1). An increased lead content in the alloy improves ease of  
7 use and reduces leaks, and solder containing 40-50% lead by weight was used in US  
8 buildings until banned in 1986. Thereafter, only “lead-free” solder, containing less than  
9 0.2% lead by weight, was allowed in buildings. Unfortunately, lead solder is still  
10 available in hardware stores because it is legal for use in hobby electronics, and plumbers  
11 still illegally use lead solder in some new buildings in the US (Goss, 2008) and in  
12 Scotland (Ramsay, 2003). In fact, a Scottish study found links between illegal use of  
13 leaded solder in new homes and blood lead of residents (Ramsay, 2003). The  
14 contribution of lead solder to lead in water at a given tap is extremely variable, and is  
15 dependent on the number of joints, their age, workmanship when the joint was created,  
16 surface area of the solder exposed to water at each joint and the water chemistry (Sandvig  
17 et al., 2008). Recent cases of childhood lead poisoning from drinking water in North  
18 Carolina and in Maine were tied to lead solder particles that corroded and detached into  
19 the water supply (Triantafyllidou et al., 2007).

20  
21 **Brass (and bronze) plumbing components.** Brass and bronze are copper alloys that  
22 contain lead. Historically, lead was added to these alloys to reduce leaks (Showman  
23 1994). According to congressional definition, “lead-free” brass components (e.g.,  
24 strainers, check valves, water meters, couplings, fittings, faucets, drinking fountains,  
25 bubblers and water coolers) used in modern homes can legally contain up to 8% lead by  
26 weight (Figure 1). The contribution of a brass component (e.g., a faucet) to lead levels  
27 measured at the tap depends on the lead content of the brass (typically ranging from 1.5-  
28 8% by weight), the volume of water in contact with the faucet, the physical configuration  
29 of the faucet and how it was manufactured, water corrosivity and water flow conditions  
30 (Sandvig et al., 2008).

31  
32 Recent problems with persistent lead contamination of tap water (up to 300 µg/L lead) in  
33 new buildings at the University of North Carolina at Chapel Hill were attributed to “lead-  
34 free” brass/bronze ball valves, installed before drinking water fountains. Locating and  
35 removing these ball valves was necessary to eliminate the lead problems at the fountains  
36 (Elfland et al., 2010). There are also case studies, in which elevated lead in water from  
37 brass was suspected to be the primary contributor to cases of childhood lead poisoning  
38 (CDC, 1994). Sampling of homes in the Netherlands also revealed some severe cases of  
39 high lead release (up to 5030 µg/L) from brass faucets (Slaats et al., 2007). New brass  
40 alloys have been developed that contain very low lead (0.1-0.25% lead by weight)  
41 (Sandvig et al., 2008), and California and several other US states are beginning to require  
42 their use in new construction (Sandvig et al., 2007).

43  
44 **Other lead sources in tap water.** Galvanized pipes are steel pipes coated with a  
45 protective layer of zinc, and high levels of lead can be present as impurities in the zinc  
46 coating (Shock et al. 1996). The iron rust in these pipes can also accumulate and store

1 lead from other plumbing sources (HDR Engineering, 2009). Thus, even after lead pipe  
2 is replaced, lead accumulated in this iron rust can contribute elevated lead to tap water for  
3 years (HDR Engineering, 2009).

4  
5 **Rough estimation of US households at potential risk due to the presence of lead-**  
6 **bearing plumbing materials, and occurrence of lead pipe in other countries.** While  
7 poor record keeping makes it practically impossible to determine the exact type of  
8 plumbing materials at individual US households, without exhuming and forensically  
9 evaluating plumbing materials underground and in walls, consideration of rough  
10 estimates is useful. Weston and EES (1990) determined through anonymous surveys of  
11 water utilities, that there were about 3.3 million lead service lines and 6.4 million lead  
12 pipe gooseneck connections in the US (Table 1). For solder, it is estimated that 81  
13 million US housing units constructed prior to the federal ban of lead pipe and lead solder  
14 in 1986 (US Census, 2010) are virtually certain to contain lead solder joints (Table 1). In  
15 addition, all housing units built after 1986 are almost certain to have “lead free” brass  
16 plumbing devices that contain 1.5-8% lead by weight (Table 1). Only new housing units  
17 that incorporate non-leaded brass faucets and other non-leaded brass components (<0.1%  
18 lead by weight), can completely eliminate the presence of lead in plumbing, and it was  
19 only recently that such products could be purchased in non-leaded forms. It should be  
20 noted that the rough estimates presented (Table 1) refer to potential risk, and that like  
21 lead paint, degradation of leaded plumbing via corrosion and flaking of scale or rust to  
22 the water can dramatically increase the hazard to residents. In some situations lead in  
23 water for homes containing lead pipe, lead solder and/or leaded brass is virtually below  
24 detection, due to formation of protective surface coatings.

25  
26 To offer an additional perspective, simple calculations suggest that the mass of lead  
27 present in a typical lead service line is about 19 kg (Table 1). If only 0.1% of this lead  
28 pipe is “eaten away” at the pipe wall due to corrosion and is released to the water, the  
29 released lead mass of 19 grams is sufficient to contaminate every drop of water used by a  
30 US family of three for 3 years over the federal action level of 15 µg/L (calculation based  
31 on 1135 L/day water usage for the whole family). Before half the pipe wall (i.e., 50% of  
32 the lead pipe) is eaten away, likely subjecting the lead pipe to leaks and mandatory  
33 replacement with unleaded materials, the potential lead release is sufficient to  
34 contaminate every drop of water used by a family for 1,500 years. Coupled with the  
35 direct path to possible human ingestion, this analysis puts the potential magnitude of the  
36 lead pipe problem into perspective, and highlights the importance of corrosion control  
37 and safe water use practices in avoiding potentially harmful exposure. In 1993, the US  
38 EPA estimated that more than 40 million US residents used water that can contain lead in  
39 excess of the federal action level of 15 µg/L (US EPA, 1993).

40  
41 Lead pipes are more common in other countries. For example, the percentage of lead  
42 service lines in France, UK and Germany as of 1999 was estimated at 40-50% (Hayes  
43 and Skubala, 2009). As of 1999, premise (building) plumbing in Portugal, France and  
44 UK also contained 30-40% lead pipes (Hayes and Scubala, 2009). In Japan, as of 2002, a  
45 total of 667 km lead pipe were found below roads and 3,248 km of lead pipe were found  
46 in residential areas (Osawa, 2002).

1  
2 **Other sources of environmental lead exposure and perceptions regarding their**  
3 **relative importance.** Lead products have been used in numerous other applications, all  
4 of which constitute potentially harmful exposure sources worthy of mitigation. Before  
5 improvements in corrosion control reduced lead in potable water in the 1950's and then  
6 again in the 1970's (Karalekas et al., 1976; Moore et al., 1985), it was widely accepted  
7 that lead in water was a dominant pathway of human exposure and that high incidence of  
8 miscarriages, infant and even adult mortality were attributable to this source (Troesken,  
9 2006; Renner, 2007). While it is accepted that exposure to lead from any source is  
10 potentially harmful, maximizing public health gains with scarce available financial  
11 resources has necessitated creation of a modern hierarchy of perceived risk and reward  
12 for public health interventions. This, in turn, has occasionally put the different lead  
13 sources in competition with one another.

14  
15 EPA has recently acknowledged the fear of certain individuals that "the focus on lead in  
16 drinking water reduces attention on other and, potentially more important, sources of lead  
17 in the household environment (e.g., paint, dust)" (Blette, 2008). This mindset reinforces  
18 reports that in the early 1990's the then CDC director of the former Center for  
19 Environmental Health "...railed against doing much in drinking water because he did not  
20 want to disarm lead in paint" (Powell, 1999). There has been some speculation that the  
21 scientific presentation of research results and public health messaging, in response to a  
22 well-publicized incident of elevated high lead in drinking water of Washington, DC, was  
23 affected by these concerns (US Congressional report, 2010; Edwards, 2010). On  
24 occasion, the lead paint: water risk: reward analysis has been invoked to justify diverting  
25 a portion of funding originally intended for reducing the public's exposure to lead in  
26 water, towards creation of lead paint educational programs (Renner, 2010). It is  
27 important to acknowledge these issues, because neither scientists nor popular perception  
28 can be assumed to be completely immune from bias, and continued debate about where to  
29 invest scarce resources will intensify with reduced availability of funding.

30  
31 Clearly, peeling lead paint chips and associated dust pose a great health concern to US  
32 children (Levin et al., 2008; Jacobs 1995). Although the conventional wisdom in the US  
33 is that lead-based paint is the predominant source of lead poisoning in children, and all  
34 other lead sources are a distant second, a few potential weaknesses in this argument and  
35 alternative perspectives have been provided by authors such as Mielke and Reagan  
36 (1998). Based on their work, lead in soil and in dust, even when deteriorating lead paint  
37 is not a contributing factor (e.g., soil contamination attributable to smelter emissions, past  
38 use of leaded gasoline and other sources), can be an equally important exposure pathway,  
39 compared to lead paint that is deteriorating in place (Mielke and Reagan 1998). Much  
40 has been done to address all environmental lead sources, and much more needs to be  
41 done. Since 1977 the Consumer Product Safety Commission (CPSC) has limited the lead  
42 content of paint in the US to 600 parts per million (or else 0.06% by dry weight of the  
43 paint), but older residences may have paint present with much higher lead content (up to  
44 50% lead before 1955) (ATSDR, 2007). The US EPA's Office of Chemical Safety and  
45 Pollution Prevention also recently issued the lead renovation, repair and painting rule to  
46 protect against exposure from renovations that disturb lead-based paint (US EPA, 2010).

1 After the landmark phase-out of commercial leaded gasoline, which was completed in  
2 1995, 78% of air lead in the US is attributed to industrial emissions (Levin et al., 2008).  
3 The US EPA has set an enforceable national quality standard for lead in ambient air,  
4 while the Occupational Health and Safety Administration (OSHA) has set an enforceable  
5 permissible exposure limit for lead in workplace air (ATSDR, 2007). Lead is also present  
6 in consumer products. Dietary supplements, crystal glassware and ceramic pottery,  
7 polyvinyl chloride (PVC) miniblinds, synthetic turf, imported candy and foods, and  
8 imported children's toys have been found to contain high levels of lead (Levin et al.,  
9 2008). The CPSC has recalled thousands of imported products, including children's toys,  
10 which contained lead and did not meet US standards (Levin et al., 2008).

11  
12 While the conventional wisdom is that lead in paint and in dust account for a majority of  
13 EBLs in US children, the CDC estimated that 30% or more of current EBL cases do not  
14 have an immediate lead paint source identified (Levin et al., 2008). The EPA (EPA,  
15 2010) has recently expressed an opinion, shared by many others (Levin et al., 2008,  
16 Scott, 2009), that "as other agencies and EPA offices focus primarily on other sources of  
17 lead exposure (e.g. lead-based paint, lead in dust and soil, etc.) lead in drinking water as  
18 an exposure path is becoming a bigger percentage of a smaller number" (EPA, 2010).

### 19 III. INTENT AND LIMITATIONS OF US REGULATIONS/GUIDELINES 20 FOR LEAD IN TAP WATER, AND OTHER RELEVANT PUBLIC 21 HEALTH GUIDANCE 22

23 **Lead and Copper Rule (LCR) of 1991.** The US Environmental Protection Agency  
24 (EPA) regulates public water supplies under the Lead and Copper Rule (LCR) through an  
25 "action level" for lead at home taps of 15 parts per billion ( $\mu\text{g/L}$ ) (US EPA, 1991). If  
26 lead concentrations exceed this action level (AL) in more than 10% of customer taps  
27 sampled, the water utility must take measures to control plumbing corrosion and inform  
28 the public about steps they should take to protect their health (Table 2). The EPA has  
29 also set a maximum contaminant level goal (MCLG) of zero for lead at the tap. As an  
30 MCLG, this guideline is not enforceable, but represents the optimal lead-in-water level  
31 below which there is "no known or expected risk to health".  
32

33 Implementation of the LCR in 1991 significantly controlled lead contamination at the tap,  
34 as evidenced by a recent review of monitoring data from homes in many large US cities.  
35 The review showed that 96% of US utilities were below the lead AL of 15  $\mu\text{g/L}$  (US  
36 EPA, 2006a). The LCR replaced the previous standard of 50  $\mu\text{g/L}$ , which was ineffective  
37 because it measured lead at the entry point to the distribution system and before contact  
38 with lead containing plumbing (Figure 1). The LCR requires sampling at homes known  
39 to have plumbing with highest potential for lead contamination, and after a minimum of 6  
40 hours in which the sampled water has to contact the plumbing (US EPA, 1991).

41  
42 Obviously, reliance on the 90%ile lead level to determine compliance with the LCR  
43 means that there is no maximum contaminant level (MCL) for lead in consumers' water  
44 to meet the Federal regulation. The US EPA explicitly acknowledged this in 1991, by  
45 stating that "the AL does not determine the compliance status of a system as does an

T  
145

1 MCL, but merely serves as a surrogate for a detailed optimization demonstration” (US  
2 EPA, 1991). The EPA further clarified that the LCR “is aimed at identifying system-  
3 wide problems rather than problems at outlets in individual buildings” and that “the 15  
4 µg/L action level for public water systems is therefore a trigger for treatment rather than  
5 an exposure level” (US EPA, 2006).

6  
7 To illustrate, consider actual lead-in-water data for consumers in a large US city living in  
8 homes that are not necessarily at high risk, and which has been in consistent compliance  
9 with the LCR (i.e., 90<sup>th</sup> percentile lead in water =10 µg/L < 15 µg/L) (Figure 3). One  
10 percent of the population is exposed to over 70 µg/L lead, and 0.1% of the population is  
11 exposed to lead over 1717 µg/L. If the US goal of eliminating EBL in all children by  
12 2020 is to be achieved, the higher risk at the upper tail of the WLL distribution needs to  
13 be acknowledged and remediated. Consistent with the above points, it is not surprising  
14 that a recent case of lead poisoning was attributed to lead contaminated tap water in  
15 Durham, North Carolina, even though the city was compliant with the LCR  
16 (Triantafyllidou et al., 2007). Unfortunately, because the LCR is designed to monitor  
17 effectiveness of corrosion control and does not protect individual consumers, only 100  
18 homes must be tested in large cities (USEPA, 1991), which translates to far less than 1  
19 out of 1,000 households. The key point of this discussion is that compliance with the  
20 LCR lead action level does not guarantee, or even imply, that all individuals in the city  
21 are protected from lead-in-water hazards.

22  
23 Moreover, LCR testing loopholes may allow high lead levels to be “missed”, either  
24 accidentally or intentionally, in the relatively small number of homes that are sampled  
25 (Renner, 2009; Scott, 2009). For example, failure to pick the worst-case houses, not  
26 allowing water to stagnate long enough inside the plumbing before sampling, removing  
27 the faucet aerator screen before sampling, or sampling in cooler months, can allow  
28 compliance with the LCR AL for lead, and effectively hide serious water contamination  
29 (Renner, 2009). Sampling practices that can “miss” lead-in-water hazards have been  
30 employed in major US cities (Leonnig, 2004), although it is the authors’ experience that  
31 the majority of US water utilities sample tap water and report monitoring data with the  
32 safety of their consumers in mind.

33  
34 **Lead Contamination Control Act (LCCA) of 1988.** The LCR also applies to the 10%  
35 of US schools that have their own water supply (Table 2). However, it does not extend to  
36 the majority of US schools and daycare facilities, which rely on public water systems for  
37 their water supply (Table 2). Instead, the Lead Contamination Control Act (LCCA)  
38 provides non-enforceable guidelines for these schools and daycare facilities,  
39 recommending that drinking water should not exceed 20 µg/L lead in any 250 mL first-  
40 draw sample (US EPA, 2006) (Table 2). In other words, aside from the 10% of US  
41 schools that are regulated as public water systems under the LCR due to use of their own  
42 water supply or well, the remaining 90% of US schools and daycare facilities are not  
43 subject to any enforceable national lead-in-water standard (Table 2).

44  
45 The recommended guideline of 20 µg/L applied to lead in school water is considered  
46 more stringent than the 15 µg/L lead action level for homes, because a 250 mL water

1 sample under the LCCA tends to concentrate the lead in collected samples, compared to  
2 the 1-L samples collected under the LCR (US EPA, 2010). Passage of the LCCA in 1988  
3 prompted many schools to test for lead in drinking water, but state adoption and  
4 enforcement of the guideline was often weak and even nonexistent (Lambrinidou et al.,  
5 2010). By 1990 many schools had not repaired or removed lead-tainted coolers, used  
6 sampling protocols other than that recommended by EPA, carried out very limited or  
7 inappropriate sampling, or failed to conduct water testing at all (Lambrinidou et al.,  
8 2010).

9  
10 A recent investigative report by the Associated Press (Burke, 2009) and subsequent  
11 congressional hearing (Freking, 2009) revealed problems with high lead in water of  
12 hundreds of schools regulated as public water systems under the LCR. In response, the  
13 EPA has stated it plans to better address and enforce lead standards in such situations  
14 (Freking, 2009). Although much less information is available for the 90% of schools not  
15 subject to any sampling requirements, case studies in Baltimore MD, Seattle WA,  
16 Philadelphia PA, Washington DC, Maryland suburbs and Los Angeles CA revealed  
17 serious problems with lead contamination of school water in recent years (Table 3). In  
18 the vast majority of these cases, lead-in-water hazards were not revealed by the schools  
19 under the LCCA, but by parents/students or investigative reporters (Table 3). With only  
20 one exception, at least three years elapsed from the time the schools recognized a  
21 problem to the time the public was informed. Another key point is that a large  
22 percentage of taps in some of the schools (up to 80%) had lead in water above the LCCA  
23 standard of 20 µg/L. In addition, some schools had taps dispensing water with lead-  
24 levels exceeding “hazardous waste” criteria (i.e., > 5,000 µg/L lead) (Table 3).

25  
26 Remedial measures in these school systems varied from replacing bubbler heads or  
27 installing new fountains to installing filters, flushing, turning off fountains, and providing  
28 bottled water (EA Engineering, Science and Technology, 2007; Boyd et al., 2008b;  
29 Greenwire, 2004, Montgomery County Public Schools, 2007; Grover, 2008c). These  
30 remedial measures invariably relied on a “trial and error” approach. Thankfully, some of  
31 these school systems appear to have resolved the majority of lead-in-water problems, at  
32 least in the short-term. However, remediation sometimes involved millions of dollars to  
33 replace fixtures and fountains, only to have the problem return a few months later (Bach,  
34 2005). Like lead paint, lead in water problems can never be considered fully resolved,  
35 until the lead-bearing materials have been completely removed. It is also worth noting  
36 that the schools described in Table 3 represent the “good news,” since most other school  
37 systems in urban areas have not systematically tested their water for lead in nearly three  
38 decades. Not shown in Table 3, are other case studies from: 1) Davidson, NC where a  
39 problem was discovered after a high school chemistry experiment failed and the teacher  
40 eventually traced it to high lead (Edwards, 2007), 2) Durham, NC where sampling  
41 revealed hazardous lead levels in some water fountains at 8 schools (Biasecker, 2006)  
42 and 3) cases in New Jersey (Burney and Dwight, 2003).

43  
44 The limited attention on lead in drinking water of schools and day-care facilities is  
45 disconcerting, given the potential public health risk. First, school children are much more  
46 vulnerable to adverse health effects from lead exposure relative to adults (Needleman,

1 2004). Second, the intermittent pattern of water consumption, with periods of little or no  
2 water use on weekends, holidays and over summer break, produces very long stagnation  
3 periods of water inside the piping and can be worst case for releasing hazardous levels of  
4 lead from the plumbing into the water supply (Levin et al., 2008). Finally, school  
5 buildings have intricate plumbing systems, sometimes very old, containing multiple  
6 potential sources of water lead contamination. In 2004, the US EPA requested  
7 information and compiled a summary of state programs, regarding implementation of  
8 LCCA guidance (US EPA, 2004). More recently, acknowledging the lack of information  
9 on drinking water of schools, the US EPA announced that it is developing a draft "Charge  
10 on Safer Drinking Water in Schools and Child Care Facilities Initiative" that will seek  
11 input on how to assess the risks of lead in school drinking water (US EPA, 2010).  
12

13 Despite these recently acknowledged problems with elevated lead in school water, one  
14 analysis that was conducted to examine the health risks, suggested that there was little  
15 cause for concern. Sathyanarayana et al. (2006) simulated typical-case and worst-case  
16 scenarios of drinking water consumption at Seattle schools, and predicted reassuring  
17 blood lead levels for school children of below 5.0  $\mu\text{g}/\text{dL}$  in all cases. However, these  
18 authors dismissed the highest detected lead-in-water measurements as unrepresentative,  
19 and only considered the geometric mean blood lead level of the student population using  
20 a bio-kinetic model. It is likely that explicit consideration of the highest measured lead-  
21 in-water samples, and resultant impacts on blood lead of more sensitive children as  
22 opposed to only the geometric mean (i.e., the 50<sup>th</sup> percentile of blood lead levels), would  
23 indicate a much more serious risk. In support of this hypothesis, it was recently revealed  
24 that a child with elevated blood lead from water in Greenville, NC was exposed in a day  
25 care center (Robertson, 2006), and environmental assessments in Washington DC  
26 attributed a child's elevated blood lead to contaminated water (7,300  $\mu\text{g}/\text{L}$  lead) at an  
27 elementary school (Lambrinidou et al., 2010). Concerns related to a case of adult lead  
28 exposure for a teacher in an Oregon school in 2008, gave impetus to testing of tap water  
29 for water fountains at work which revealed high lead in water (Lambrinidou, 2008).  
30 Reports of harmful exposure are more consistent with common sense expectations,  
31 considering that the higher levels of lead detected in some schools (Table 3) indicate that  
32 a single glass of water can contain up to 29 times more lead than that deemed to  
33 constitute an acute health risk according to the CPSC (i.e., 20,000  $\mu\text{g}/\text{L}$  lead in a 250 mL  
34 sample constitutes a single dose of 5000  $\mu\text{g}$  lead, while the CPSC criterion is set at 175  
35  $\mu\text{g}$  lead).  
36

37 **Unregulated drinking water systems.** About 15% of Americans operate their own  
38 private drinking water supplies (e.g., private wells and cistern type systems) (US EPA,  
39 2006c). These systems are not subject to federal standards for lead monitoring (and other  
40 contaminants), although the major lead sources are similar to those found in public water  
41 supplies (Table 2). As a result, the magnitude of lead-in-water problems at these homes  
42 and the potential public health risks have not been studied (Schock et al., 1996).  
43

#### 44 **Other public health guidance as it relates to lead contamination of tap water**

45 The LCR and LCCA lead limits were derived from an estimation of lead concentrations  
46 considered at the time economically and technologically feasible to achieve, and as such,

1 are not entirely health-based (Lambrinidou et al., 2010). A compilation of other health-  
2 based thresholds (Table 4) indicates that the US EPA Maximum Contaminant Level Goal  
3 (MCLG) for lead in water is equal to zero and that the state of California has developed  
4 its own Public Health Goal (PHG) for lead in water at 2 µg/L. The US EPA at one time  
5 indicated that 40 µg/L lead in water poses an “imminent and substantial endangerment to  
6 children” (Table 4). Health Canada (1992) and the World Health Organization (1993)  
7 have both developed a health-based guideline of 10 µg/L lead for drinking water, while  
8 the CDC (2010) advises children and pregnant women to not consume water that contains  
9 more than 15 µg/L lead (Table 4). As a further point of reference, the US Consumer  
10 Product Safety Commission (CPSC) classified a lead dose of 175 µg as an “acute health  
11 risk” to children (CPSC, 2005). This CPSC standard was used as a trigger for recalling  
12 millions of children’s toy jewelry (CPSC, 2005). If this standard, which was applied to  
13 children’s jewelry and toys (products not intended for human consumption), was applied  
14 to lead in water (a product intended for human consumption), the one-time ingestion of  
15 250 mL of water at 700 µg/L lead (resulting in a lead dose of 175 µg) would also be  
16 classified as an “acute health risk” to children (Table 4). Finally, water containing more  
17 than 5,000 µg/L lead exceeds “hazardous waste” criteria (US EPA, 2009).

#### 18 IV. FORMS OF LEAD IN TAP WATER AND IMPLICATIONS FOR 19 MONITORING AND EXPOSURE

20  
21 **Dissolved versus particulate lead in tap water.** Lead that is released from plumbing  
22 into drinking water can be present in a variety of distinct physicochemical forms  
23 including free aqueous ions, inorganic complexes, organic complexes, associations with  
24 highly dispersed colloidal matter, suspended particles of insoluble salts, or adsorbed on  
25 inorganic particulates (De Rosa and Williams, 1992). In some practical tests, the total  
26 lead content of drinking water is often demarcated into two fractions: the “dissolved  
27 lead” fraction and the “particulate lead” fraction (Table 5). Dissolved lead is  
28 operationally defined as the fraction of total lead in water that is small enough to pass  
29 through a filter of 0.45 µm pore size (Mc Neill and Edwards, 2004). Particulate lead is  
30 the fraction of total lead in drinking water that is retained by a filter of 0.45 µm pore size  
31 (Table 5). At the upper end of particulate lead sizes, these particles are big enough to be  
32 seen by the naked eye.

33  
34 Lead particles in tap water can originate from detachment of lead-bearing scale or rusts  
35 from plumbing, or by scouring/sloughing-off during water flow (Schock, 1990). Lead  
36 corrosion rusts in water plumbing materials are analogs of peeling lead paint, in that  
37 degradation of the underlying plumbing material can dramatically increase the creation of  
38 these particles, their detachment, and resulting human exposure. Indeed, the  
39 mineralogical forms of many lead rusts (i.e., cerussite and hydrocerussite, see Table 5)  
40 are identical to those lead paint. Lead particles in tap water may also originate from  
41 physically degraded pieces of leaded brass, lead solder or lead pipe (Triantafyllidou et al.,  
42 2007). Unlike the case of dissolved lead in water, which is not controlled by nuances of  
43 water flow from the tap, the mobilization of particulate lead from plumbing can be highly

1 variable, depending on changes in pressure and water flow velocity/direction (Schock,  
2 1990).

3  
4 Numerous investigators have reported lead particles in water. Flaking lead particles  
5 larger than 12  $\mu\text{m}$  in diameter were observed detaching from pipe, along with colloidal  
6 lead fractions associated with iron oxides and humic acids (De Mora et al. 1987; De Rosa  
7 and Williams, 1992). An extensive British survey reported that the flaking lead problems  
8 were caused by large black/brown particles visible to the consumer, whereas colloidal  
9 lead problems were caused by smaller particles that were not visible (De Rosa and  
10 Williams, 1992). The British report further concluded that problems with particulate lead  
11 were often associated with the presence of iron particulates, and that these problems were  
12 exacerbated by high water flows, especially during periods of high water demand (i.e., in  
13 the summer), as was recently highlighted in the US (HDR Engineering, 2009).

14  
15 A small survey of lead in potable water from around the US revealed numerous instances  
16 in which lead was also present as particulates, sometimes at concentrations greater than  
17 1,000  $\mu\text{g/L}$  (McNeill and Edwards, 2004). Particulate lead was also clearly demonstrated  
18 to detach from lead-tin solder joints (Bisogni et al., 2000) and from lead pipes  
19 (Triantafyllidou et al., 2009a) in laboratory test rigs. In these laboratory studies,  
20 particulate lead was the predominant form of lead, comprising up to 99% of the total lead  
21 concentration in water samples (Triantafyllidou et al., 2009a).

22  
23 Field investigations at various US locations with significant lead-in-water problems  
24 revealed that particulate lead release from the plumbing was often the cause (Figure 4;  
25 Table 6), and in some cases the source of the lead problem could be forensically linked to  
26 either lead pipe, lead solder or leaded brass (Table 6). A key point is the extraordinarily  
27 high levels of lead (up to 190,000  $\mu\text{g/L}$ , or else more than 12,000 times the EPA action  
28 level) occasionally present in the water due to these particles, and their varying  
29 mineralogical content ranging from 3% to 100% lead (Table 6). The massive lead  
30 contamination occasionally resulting from partial lead pipe replacements is especially  
31 noteworthy, in light of the CDC report of EBL in Washington DC children (Frumkin,  
32 2010).

33  
34 **Implications of particulate lead in tap water for monitoring, exposure assessment**  
35 **and corrosion control.** Chemical lead solubility models, human exposure models, water  
36 sampling protocols, and analytical quantification methods are often based on the  
37 presumed dominance of dissolved lead in drinking water. It has only recently been  
38 recognized that particulate lead can occasionally be the dominant form of lead in drinking  
39 water (Triantafyllidou et al., 2007). A preliminary synthesis (Table 6) indicates that such  
40 problems may not be an isolated occurrence, especially given the rarity of such  
41 measurements.

42  
43 It is useful to highlight some of the challenges associated with the presence of particulate  
44 lead in tap water, in terms of environmental monitoring and exposure. All models  
45 predicting lead at the tap, do so by considering soluble lead (Schock, 1990). Because the  
46 release of particulate lead in drinking water is often caused by physical factors and is  
47 erratic, its contribution is impossible to predict (Schock, 1990). At the same time,

12/150

1 capturing actual particulate lead spikes in tap water via field sampling is very  
2 challenging. Schock et al. (2008) warned that if lead (and other contaminants) were  
3 mobilized into solution or released as particulates, this would result in long-term  
4 intermittent exposures of unknown impact that can easily go undetected.

5  
6 Particulate lead in water can be ingested, and presumably be dissolved or mobilized by  
7 human stomach acid (Schock, 1990). Mahaffey (1977) reported that lead absorption  
8 from small lead particles is greater than lead absorption from large particles. However,  
9 she also reported that when large pieces of lead are ingested, they may lodge in the  
10 gastrointestinal tract, and cause severe lead poisoning as they slowly dissolve.  
11 Bioavailability tests on lead solder particles collected from homes of lead-poisoned  
12 children in Greenville, NC and Durham NC, revealed that a significant fraction of the  
13 particulate lead from solder dissolved in simulated gastric fluid (Triantafyllidou et al.,  
14 2007). Additional case studies of childhood lead poisoning in Maine and in Washington  
15 DC (Table 6), which were attributed to lead-bearing particles that detached from the  
16 plumbing and contaminated tap water, also provide unambiguous proof that these lead  
17 particles were indeed bio-available once ingested.

18  
19 In order to protect consumers from such exposures, corrosion control programs need to  
20 account for/prevent particulate lead release into the water. Modern corrosion control  
21 strategies were designed to reduce leaching from lead pipe, solder and brass materials by  
22 encouraging formation of low solubility lead hydroxyl-carbonate and phosphate films on  
23 the plumbing material surface, which can limit contamination to flowing water. But  
24 control of particulate release is dependent on minimizing the destabilization of the  
25 protective rust layer from water quality changes or hydraulic disturbances, and this  
26 process is poorly studied. The drinking water industry currently lacks the tools or  
27 knowledge to completely prevent or control particulate lead release.

## 28 **V. BLOOD LEAD LEVEL AND MAJOR LEAD TOXICITY MECHANISMS**

29  
30 Potential harm from exposure to lead is typically tracked by measurements of the blood  
31 lead level (BLL). BLLs above 10 µg/dL are considered elevated (EBLLs) for infants and  
32 children, since they exceed the Centers for Disease Control and Prevention (CDC)  
33 threshold at which detectable mental impairment and behavioral changes have been  
34 documented (CDC, 2005). Cases in which blood lead exceeds 10 µg/dL or 20 µg/dL are  
35 also termed “lead poisoning”, dependent on the specific US jurisdiction. Depending on  
36 the extent of uptake by the blood stream (Table 7), lead disturbs the heme biosynthetic  
37 pathway and can lead to anemia (Singhal and Thomas, 1980), causes kidney malfunction  
38 or even kidney failure (Loghman-Adham, 1997), but most importantly generates brain  
39 disorders in children (Needleman, 2004). Recent studies suggest that decreased IQ and  
40 cognition occur in children even at BLLs as low as 3.0 µg/dL (Jusko et al., 2008;  
41 Bellinger and Needleman, 2003), and that impaired kidney function occurs in adolescents  
42 even at BLLs as low as 1.5 µg/dL (Fadrowski et al., 2010). Emerging clinical evidence is  
43 therefore strongly reinforcing the notion that no safe level of lead exposure exists. Lead  
44 toxicity (Table 7) is notoriously difficult to diagnose, and creates a wide range of  
45 symptoms which are easily overlooked (Kalra et al., 2000).



1 have not developed programs at all (Lambrinidou et al., 2010). A recent nationwide  
2 Associated Press survey on the 10% of US schools that are subject to the LCR, revealed  
3 that lead-contaminated drinking water affects schools in at least 27 states (Lambrinidou et  
4 al., 2010). There is no scientific or practical reason to believe that the problem does not  
5 extend to other schools and to other states, which are not being monitored for lead-in-  
6 water problems.

7  
8 ***Relative exclusion of water lead measurements during assessments of lead-poisoned***  
9 ***children.*** Management strategies for childhood lead poisoning in the US have been  
10 developed based on the assumption that the LCR eliminated elevated water lead and that  
11 other environmental sources (e.g., lead in paint, dust or soil) are the most likely culprit.  
12 Current CDC guidance states that “if prior testing of a public water system shows that  
13 lead contamination is not a problem in homes served by that system, no additional testing  
14 is necessary, unless no other source of a child’s EBLL can be found” (CDC, 2002).  
15 Public health agencies routinely misinterpret compliance with the LCR action level as  
16 eliminating the need for water sampling in homes, schools or day care facilities of lead-  
17 poisoned children.

18  
19 A Virginia Tech survey in 2006 verified that drinking water sampling is not standard  
20 practice during home assessments of lead-poisoned children. From the seventeen states  
21 that responded to the survey, only two required water testing in all cases of EBLL. Three  
22 of the jurisdictions “often” tested the water, eight of the jurisdictions “sometimes” tested  
23 the water, while four said they “never” did. A follow-up survey by the Alliance of  
24 Healthy Homes (Scott, 2009) revealed that in a state with a severe lead-poisoning rate  
25 “water is tested when no lead paint violations are identified, but this is virtually never”.  
26 Another state with similar problems claimed to “occasionally do this [test the water] if it’s  
27 the only way to convince the parents that the real hazard is lead-based paint in their  
28 home” (Scott, 2009). A different survey by the CDC (Renner, 2009) showed that fifteen  
29 lead grantee municipalities “routinely” collected water samples during home inspections,  
30 and that sixteen “sometimes” sampled drinking water (if lead was not found in paint/dust,  
31 or if drinking water was provided by a private well/ unregulated water system), while  
32 seven “never” tested drinking water.

33  
34 Even when sampling is conducted, the CDC does not provide specific guidance on when  
35 and how to test water for lead (Renner, 2009). If a water sample is taken at all, it is  
36 typically a flushed sample taken during the inspection. This means that in the few  
37 instances where health agencies do collect tap water at homes of lead poisoned children,  
38 they are usually not collecting “worst-case” samples, and are thus not capturing worst-  
39 case lead-in-water exposures (Renner, 2009).

40  
41 **WLL measurements do not always reflect actual lead in water.** In order to assess the  
42 public health risk from elevated lead in tap water, it is obviously necessary to first  
43 measure the actual lead content of the water. But lead-in-water measurements can be  
44 controlled by the season, day, hour of measurement, and subtle differences in sample  
45 collection procedures can either detect or completely miss lead spikes (Table 8).

46

1 *Improper water sampling/preservation methods at “high-risk” taps may miss some of*  
2 *the lead present in water.* Standard sampling/analytical protocols are adequate in  
3 quantifying lead in water in the typical case. In exceptional cases, e.g. when childhood  
4 lead poisoning may be caused by water, the detection of lead hazards can be critically  
5 dependent on the specifics of sampling.

6  
7 Flow rate during sample collection. The most recent guidance for schools (EPA, 2006)  
8 suggests to “induce a small (e.g., pencil-sized) steady flow of water from the outlet”.  
9 These instructions translate to an unrealistically low flow rate of less than 1 L/min. Yet  
10 every-day water consumption typically employs higher flow rates, at which it has been  
11 long known that the water may physically scour lead deposits from the pipe (Britton &  
12 Richards, 1981; Schock, 1990). Sampling at a higher flow rate would therefore more  
13 likely capture lead spikes due to particulate lead release, and would be more  
14 representative of typical water usage. Collecting water from a “high-risk” tap at the  
15 EPA-recommended low flow rate “missed” 90% of the particulate lead present (Edwards,  
16 2005), during a home investigation in Washington DC in 2006 (Figure 5).

17  
18 Sampling of hot versus cold water. Existing protocols under the LCR and lead poisoning  
19 case management only require sampling of cold tap water. Instead of sampling hot tap  
20 water, which is occasionally known to contain much higher lead, the EPA (2006) simply  
21 recommends that consumers never drink hot water or use it for cooking. A case study in  
22 Australia, where three individuals were diagnosed with lead poisoning, revealed that hot  
23 tap water contained 260 times more lead than did cold tap water (Mesch et al., 1996).  
24 The family members used hot water to prepare instant coffee and to cook. In another  
25 Australian study, water was collected from water boilers, coffee machines from  
26 restaurants, offices, workplaces and schools. Excessive levels of lead were found in 67%  
27 of the samples, probably due to the contact of brass components with the hot water  
28 (McCafferty et al., 1995). In Washington DC, review of environmental risk assessments  
29 in the homes of children with elevated BLLs during 2006-2007, revealed that more than  
30 50% of caregivers who were asked, stated that they had used unfiltered hot tap water to  
31 mix infant formula, powdered milk, and juice (Lambrinidou and Edwards, 2008).  
32 Clearly, individuals consume hot tap water even though advised not to, and this risk is  
33 not quantified.

34  
35 Sample Preservation. Existing analytical methods are based on the assumption that lead  
36 in water is dissolved, and that standard preservation of water samples at  $\text{pH} \leq 2.0$  with  
37 addition of 0.15% nitric acid is adequate for detecting all the lead that is present in the  
38 water. Digestion of samples with heat or stronger acid is not required unless turbidity  
39 exceeds certain thresholds (EPA, 1994). Edwards and Dudi (2004) first showed that the  
40 standard EPA preservation protocol can sometimes “miss” much of the lead that is  
41 actually present in water. For instance, water samples actually containing 508  $\mu\text{g/L}$  lead  
42 in Washington DC, only measured as 102  $\mu\text{g/L}$ , using the standard preservation protocol  
43 (Edwards and Dudi, 2004). The reason for the discrepancy is that particulate lead can  
44 settle or adhere to the plastic sampling containers, and is “missed” when aliquots are  
45 taken for that measurement (Triantafyllidou et al., 2007).

46

1 **Inherent variability in lead release from plumbing cannot be captured by “single**  
2 **sample” WLL measurements.** Due to spatial and temporal variability in lead release  
3 from plumbing, especially in the case of particulate lead, surveys based on a single water  
4 sample may be inadequate to characterize exposure (Matthew et al., 1981, Pocock, 1980).  
5 Yet current monitoring programs under the LCR or the voluntary LCCA are based on a  
6 single water sample from each outlet, due to practical and financial constraints. Schock  
7 (1990) warned that if water monitoring programs do not account for this inherent  
8 variability, then the measurements will be unrepresentative and irreproducible.  
9

10 Spatial Variability. Lead-in-tap water fluctuations are possible within a city (see Figure  
11 4), a neighborhood, or a single home, even if water is collected under a standard protocol.  
12 For example, infrequent water consumption in municipal buildings or in schools, with  
13 periods of little or no usage during weekends and breaks, results in long stagnation  
14 periods of the water inside the piping and causes it to undergo chemical changes (Levin,  
15 2008). This translates to more variability in the lead concentration, compared to homes  
16 where water consumption is much more frequent and regular. In addition, pH or other  
17 chemical fluctuations, depending on how far from the treatment plant water is transported  
18 in order to reach consumer’s taps, also affects its corrosivity to leaded plumbing.  
19 Physical factors, such as the several interconnecting lines within a household plumbing  
20 system which route water to exterior faucets/bathrooms/kitchens/utility rooms, and the  
21 presence and type of leaded plumbing (e.g. leaded solder, leaded brass faucets, lead pipe)  
22 greatly affect lead levels at the tap (Schock 1990).  
23

24 Temporal Variability. Fluctuations in lead levels from a single tap, depending on season  
25 or even on time of day, are possible. Seasonal fluctuations in temperature and chemical  
26 constituents, as well as seasonal variations in chlorination practice by the water utility  
27 may cause variable corrosivity of the water entering a household plumbing system  
28 (Schock 1990). In the course of one day, first-draw water, drawn from a tap in the  
29 morning after overnight stagnation, is considered worst-case in terms of lead release from  
30 the plumbing. Flushed water, or water collected after short holding times, tend to contain  
31 lower lead levels. Pocock (1980) argued that whatever type of water sample is collected,  
32 a single sample cannot provide a reliable estimate of the resident’s exposure to water  
33 lead. To illustrate, during an environmental assessment of a lead-poisoned child in  
34 Washington DC in 2004, the DC Department of Health (DOH) concluded that drinking  
35 water was not a potential hazard, based on collection of a single flushed water sample  
36 which measured lead at a reassuring concentration of 11 µg/L. Freedom of information  
37 act (FOIA) requests revealed that in four other flushed samples collected by the local  
38 water utility, lead in water ranged between 19-583 µg/L (Table 9). The samples collected  
39 by the utility provided strong indication that elevated lead in water was a potentially  
40 serious hazard, but the health agency sampling failed to make that connection based on  
41 their collection of a single flushed sample.

#### 42 **Individual water consumption patterns affect individual exposure**

43  
44 **Variability in Individual Water Consumption Patterns.** In over-simplified terms the  
45 individual risk from lead-contaminated drinking water, or any other hazard, is also a

1 function of exposure to that hazard. Prior research has demonstrated a strong dependence  
2 between the quantity of tap water consumed and overall exposure. For example, Potula  
3 *et al.* (1999) found that Bostonians who consumed medium or high levels of tap-water ( $\geq$   
4 1 glass/day) that contained greater than 50  $\mu\text{g/L}$  of lead, developed progressively higher  
5 patella lead levels later in life, compared to those Bostonians with low levels of ingestion  
6 of the contaminated water ( $< 1$  glass/day). Similarly, Galke *et al.* (2006) determined that  
7 the more glasses of tap water consumed, the higher the chance of an elevated blood lead level  
8 for children in Milwaukee and in New York. Consumption of two glasses of tap water per  
9 day corresponded to a very high (50%) probability of having elevated blood lead (Galke  
10 *et al.*, 2006).

11  
12 Individual water consumption patterns may vary markedly between different age groups,  
13 and should be taken into consideration when assessing potential exposure. For instance, a  
14 Canadian survey on drinking water intake showed that infants less than one year  
15 consumed on average 122 mL/kg-day of water if they were formula-fed. This amount is  
16 about three times higher than the 44 mL/kg-day intake proposed by EPA (Levallois *et al.*,  
17 2008). These authors concluded that due to their high water intake on a body weight  
18 basis, formula-fed infants may be particularly susceptible to water contaminants  
19 (Levallois *et al.*, 2008).

20  
21 The use of tap, filtered tap or bottled water, also has an obvious impact. During the  
22 Washington DC lead-in-water crisis, BLLs were measured in residents of homes with  
23 water lead levels greater than 300  $\mu\text{g/L}$ . All residents had BLLs lower than the CDC  
24 levels of concern (10  $\mu\text{g/dL}$  for children and 25  $\mu\text{g/dL}$  for adults), which was at first  
25 interpreted as indicating that the high lead in water was not harmful (Stokes *et al.*, 2004).  
26 However, later analysis revealed that only a few individuals (and no children) had been  
27 consuming tap water for months prior to having their blood lead collected, and that  
28 virtually all were using lead filters and bottled water (Edwards *et al.*, 2009; Edwards,  
29 2010; CDC, 2010b). The key take away message from the "300  $\mu\text{g/L}$ " study is that use  
30 of water filters, bottled water or even flushing, can be very effective at mitigating risk.

31  
32 **Underestimated indirect contribution of water to the total dietary lead intake.** The  
33 potential for massive accumulation of lead in food during cooking is not commonly  
34 realized. Use of relatively large quantities of water to boil vegetables, pasta, or other  
35 food, and effective concentration of the lead into food via adsorption has been  
36 demonstrated (Moore, 1983; Little *et al.*, 1981, Baxter *et al.*, 1992). Specifically,  
37 vegetables can absorb 90% or more of the lead from the water they are cooked in (Moore  
38 (1983). Smart *et al.* (1981) showed that lead-in-water concentrations of 100  $\mu\text{g/L}$  could  
39 contribute 74  $\mu\text{g/day}$  of lead to the total dietary lead intake from vegetables and  
40 beverages, and at a total lead-in-water concentration of 500  $\mu\text{g/L}$  the contribution was  
41 378  $\mu\text{g/day}$ . Green vegetables, carrots, rice and spaghetti concentrated more lead than  
42 many other foods (Smart *et al.*, 1983). While humans generally absorb lead from  
43 drinking water more readily (30% to 50%) than lead from food (10% to 15%) (US EPA,  
44 1986), the concentration effect can outweigh the reduced absorption factor. In addition to  
45 the report by Mesch *et al.* (1996), in which an Australian family was poisoned by use of  
46 lead-contaminated hot tap water to prepare instant coffee and cook meals, two cases of  
47 childhood lead poisoning occurred from contaminated water, even when the children did

1 not directly consume the water. In both cases cooking of pasta, rice or potatoes was  
2 implicated as the source of the children's lead poisoning (Copeland, 2004; Triantafyllidou  
3 et al., 2007).

4  
5 **Individual risk factors affect individual response to a fixed lead dose.** Variations in  
6 age, diet and genetics will produce a range of health effects in a population, in response  
7 to a fixed lead dose from water (or other sources).

8  
9 Age. The gastro-intestinal absorption rate of ingested lead is inversely related to age.  
10 The typical lead absorption rate for infants is 50%, compared to just 10% in adults  
11 (WHO, 2000).

12  
13 Dietary Habits. Diets low in calcium and/or in iron, inadequate total calories and  
14 infrequent meals are believed to be associated with enhanced absorption of ingested lead  
15 (Shannon, 1996). In dietary experiments with twenty three adult volunteers, the lead  
16 retention from consumption of lead acetate was controlled by the type/ timing of meals  
17 and beverages (James et al., 1985). Another study determined that subjects absorbed up  
18 to 50% of the lead on an empty stomach, 14% of the lead was absorbed when taken with  
19 tea or coffee, and 19% of the lead when taken with beer (Heard et al., 1983). Much lower  
20 uptakes ( $\geq 7\%$ ) were reported when lead was ingested in the course of a meal or with  
21 large amounts of calcium or phosphate (Heard et al., 1983).

22  
23 Genetics. Genetic differences may result in different individual patterns of lead uptake  
24 and biokinetics (EPA, 2002). An increasing body of evidence suggests that tiny  
25 differences in the DNA sequence can modify the uptake, distribution, and elimination of  
26 lead by the body. For example, a 1991 study of lead workers in Germany and of  
27 environmentally exposed children in New York showed that small differences in two  
28 genes affected the absorption and excretion of lead by the participants (Wetmur et al.,  
29 1991). Another 2000 study that was performed in the Republic of Korea, with the  
30 participation of lead workers as well as persons without occupational lead exposure,  
31 reached similar conclusions (Schwartz et al., 2000).

## 32 33 **VII. SUMMARY OF STUDIES ON THE ASSOCIATION BETWEEN LEAD IN** 34 **WATER AND LEAD IN BLOOD**

35  
36 The contribution of drinking water lead to the body's lead burden (i.e., blood lead) is a  
37 subject of an extensive body of literature, which at first glance can appear contradictory.  
38 Marcus (1986) synthesized relevant studies as part of a broader evaluation of lead health  
39 effects from drinking water, and an update of that synthesis is undertaken herein.  
40 Various approaches have been used throughout the years in population studies, in an  
41 attempt to correlate water lead levels (WLLs) to blood lead levels (BLLs) (Table 10).  
42 These include, but are not limited to:

- 43  
44     ▪ Focus on the most sensitive age groups (e.g. formula-fed infants, young children,  
45     or pregnant/breast-feeding women), versus lumping different age groups together

- 1       ▪ Different types of tap water sampling to capture actual lead intake through water
- 2       consumption, versus utilization of available water lead data from other sources
- 3       ▪ Parametric correlations (assuming normal distribution of WLL and BLL) versus
- 4       non-parametric correlations
- 5       ▪ Linear regression models versus curve-linear models to fit the original WLL and
- 6       BLL data, or regression after logarithmic transformation of the original data
- 7       ▪ Exclusive focus on the contribution of WLL to BLL, versus contribution of other
- 8       environmental lead sources (e.g. lead in paint, dust, soil) to BLL as well
- 9       ▪ Association between WLL and BLL, versus association between WLL and % of
- 10      study population with EBLL

11  
12 Few studies are directly comparable, but nonetheless, critically evaluating the available  
13 literature provides useful insights.

14  
15 **Studies that found an association between WLL and BLL**

16  
17 **Association between WLL and BLL in formula-fed infants.** For infants and young  
18 children up to 5 months of age, milk, formula, and drinking water are considered highly  
19 significant sources of exposure to lead (WHO, 2000). In fact, for bottle-fed infants using  
20 reconstituted formula with tap water, about 90% of their diet by weight is actually tap  
21 water, since formula is typically prepared by adding 8 parts of water to 1 part of powder  
22 (Sherlock and Quinn, 1985). Additionally taking into account that the typical lead  
23 absorption rate for infants is 50%, compared to just 10% in adults (WHO, 2000), elevated  
24 lead in water is a very significant concern for this population group. Infants typically  
25 consume 500-1000 mL of formula per day (WHO, 2000). If the water used to reconstitute  
26 formula contains 90 µg/L of lead, an infant receiving 750 mL of such formula daily  
27 would ingest 61 µg Pb/day, based on the illustrative calculation:

28  
29 
$$\frac{90 \mu\text{g Pb}}{\text{L water}} \bullet \frac{0.75 \text{L formula}}{\text{day}} \bullet 90\% \text{ water in formula} = 61 \mu\text{g Pb/day} \quad \text{Equation(1)}$$

30  
31 In a study by Ryu et al (1983), conducted when infant formula commonly had elevated  
32 lead derived from solder, infants consuming daily formula with 61 µg Pb from 3.7-6.5  
33 months of age, had elevated blood lead levels by 5.6 months of age (Figure 6). Another  
34 group of infants, exposed to only 16 µg Pb/day through their diet did not develop  
35 elevated blood lead (Figure 6). On this basis Rye et al. (1983) concluded that a lead  
36 intake of 16 µg/day, or else 3-4 µg/kg/day, is not associated with elevations in blood lead  
37 level above 10 µg/dL. This roughly corresponds to the provisional tolerable weekly  
38 intake (PTWI) of 25 µg/kg/week (or else 3.5 µg/kg/day) set by the World Health  
39 Organization (WHO, 2000). The Ryu et al. (1983) study is unique, because it provides  
40 unambiguous results for infants whose dietary lead intake was completely controlled.  
41 Due to obvious modern ethical concerns, similar experimental studies with infants are  
42 unlikely to be repeated.

43  
44 Later studies also derived strong associations between Glasgow infants' dietary lead  
45 (mainly consisting of drinking water) and blood lead (Lacey et al., 1985). For 13 week-

1 old infants, a duplicate of their formula was collected for a week so that their total lead  
2 intake could be unambiguously quantified. A simple linear relationship between lead in  
3 water collected from kettles and infant blood lead level was derived, with a correlation  
4 coefficient of  $R^2 = 0.32$  (Table 10). This work demonstrates that due to genetic and other  
5 factors mentioned earlier, perfect correlations are not to be expected between lead in  
6 water and lead in blood, even for the most susceptible sub-population to lead exposure  
7 from water.

8  
9 An investigation by Shannon and co-authors revealed nine cases where lead poisoning  
10 occurred in Boston infants, after consuming instant formula reconstituted with lead-  
11 contaminated water (Shannon et al., 1992). In one such case, the formula was prepared  
12 each morning with first-draw water from the kitchen tap, which contained 130  $\mu\text{g/L}$  lead  
13 attributable to lead solder (Shannon et al., 1989). Other cases of elevated blood lead  
14 from consumption of formula, with no other source of lead in the child's environment,  
15 have been reported (Cosgrove et al., 1989; Lockitch et al., 1991).

16  
17 **Association between WLL and BLL in young children and adults before**  
18 **implementation of modern corrosion control.** The first survey to show a curve-linear  
19 relationship between water lead and blood lead was that of Moore et al. (1977), which  
20 yielded a correlation coefficient of  $R=0.52$  by analyzing data from different sectors of the  
21 Scottish population (Table 10). That work concluded that "*Perhaps the most important*  
22 *aspect of this problem is the effect that high water lead has on the chances of a person*  
23 *having an unduly raised blood lead level*". In that study, 18% of people with first-flush  
24 water lead  $\geq 298 \mu\text{g/L}$  had BLLs  $\geq 41 \mu\text{g/dL}$ , compared to only 0.3% of those with water  
25 lead  $< 50 \mu\text{g/L}$ .

26  
27 Sherlock et al (1984), who analyzed lead in water and lead in blood of mothers in Ayr,  
28 Scotland, reinforced Moore's notion of a curve-linear relationship (Table 10). Initially,  
29 lead in water and in blood were measured for 114 mothers during 1980-1981, when the  
30 Ayr water supply was very corrosive and lead pipes were predominant. That analysis  
31 yielded a correlation coefficient of  $R^2=0.56$  between kettle water lead and blood lead  
32 level (Table 10). After changes in water treatment were implemented by increasing the  
33 pH from 5.0 to 8.5, and after some of the lead pipes had been removed, the same analysis  
34 was repeated during 1982-1983. The sample of women in the subsequent analysis  
35 included many of the same women as the 1980-1981 analysis (Sherlock et al., 1984).  
36 Combination of both data sets yielded a correlation coefficient of  $R^2=0.65$  between kettle  
37 water lead and blood lead (Table 10). After increasing the pH of the water supply, water  
38 lead levels significantly dropped, and median blood lead levels also dropped from 21  
39  $\mu\text{g/dL}$  to 13  $\mu\text{g/dL}$ .

40  
41 A study of 321 adults in an area of France with relatively corrosive water and high  
42 incidence of lead pipe (Bonney et al., 1985) revealed that the concentration of lead in  
43 tap water was significantly correlated to the residents' BLL (Table 10). For water lead  
44 levels up to 20  $\mu\text{g/L}$ , the BLLs of both men and women remained relatively constant, but  
45 if lead in water exceeded 20  $\mu\text{g/L}$  BLLs increased substantially. Elwood et al. (1985)  
46 assessed the relative contributions of water lead, dust lead and air lead to blood lead of

1 192 women in various areas of Wales. The regression model indicated that even in areas  
2 with relatively low water lead levels for that time period, water was an important source  
3 of blood lead. An increase of lead in water from 0 to 60  $\mu\text{g/L}$ , resulted in an increase of  
4 5.5  $\mu\text{g/dL}$  in blood lead level (Elwood et al., 1985).

5  
6 Raab et al. (1987) assessed the relative contributions of water lead and dust lead to blood  
7 lead of 6-9 year-old children in a part of Edinburgh with a high incidence of lead pipes  
8 and corrosive water supply. Their resulting model, accounting for exposure to water and  
9 dust, explained 43% of the variation in blood lead levels (Table 10). Coefficients for  
10 both water and dust were significant in their model (Table 10), and the authors concluded  
11 that water lead was more important than dust in this population. A follow-up study of the  
12 same individuals in central Edinburgh eight years later, showed a dramatic decrease in  
13 both their water lead and blood lead levels, which was attributed to improved corrosion  
14 control and removal of lead pipes from plumbing (Macyntire et al., 1998).

15  
16 Maes et al. (1991) assessed the contribution of lead from drinking water, dust, soil, and  
17 paint to BLLs of 384 individuals of various ages in Hawaii. This study relied on  
18 measurements from exterior house faucets previously conducted on behalf of the  
19 Department of Health. Lead in paint, dust and soil was measured, and information on  
20 water consumption patterns and demographics was obtained through questionnaire  
21 responses of the participants. Because this population was exposed to relatively high  
22 levels of lead from water and low levels of lead from soil, dust, and paint, the authors  
23 found a stronger rank-based correlation of BLLs with WLLs ( $r = 0.53$ ), compared to  
24 other environmental sources ( $r = 0.35$  for soil,  $0.30$  for dust, and  $0.14$  for interior paint)  
25 (Maes et al., 1991). Blood samples in this study were collected more than 2 months after  
26 residents had been informed to avoid tap water, unless it tested below  $20 \mu\text{g/L}$ , and  
27 virtually no vulnerable young children ( $< 1$  year of age) were tested. Even though the  
28 work of Maes et al. (1991) was never published, it was submitted to EPA to influence  
29 formulation of the 1991 US EPA LCR, which in turn introduced modern corrosion  
30 control strategies for lead in US drinking water.

31  
32 **Association between WLL and BLL in young children and adults after**  
33 **implementation of modern corrosion control.** More recent studies, conducted after the  
34 phase-out of lead in gasoline and other lead reduction strategies, and with much lower  
35 water lead levels due to modern corrosion control, still indicate strong relationships  
36 between lead in blood and lead in water. An epidemiological study in Hamburg,  
37 Germany (Fertmann *et al.*, 2004) found a statistically significant correlation between  
38 average lead concentration in tap water and lead concentration in blood for 142 young  
39 women (Spearman's  $\rho = 0.43$ ,  $p < 0.0001$ ) (Table 10). For those women who were  
40 exposed to water lead  $> 10 \mu\text{g/L}$ , an intervention program was tested, which either  
41 involved eliminating tap water lead exposure (by consuming bottled water) or  
42 minimizing exposure (by flushing water prior to consumption). Overall, after about 10  
43 weeks of intervention, the median blood lead level decreased by  $1.1 \mu\text{g/dL}$  ( $p \leq 0.001$ ).  
44 Individuals flushing the water lowered their blood level by 21% whereas those drinking  
45 bottled water reduced their blood lead level by 37% (Fertmann *et al.*, 2004). The authors

1 concluded that “*lead in tap water stands for an avoidable surplus exposure*” (Fertmann *et*  
2 *al.*, 2004).

3  
4 In another German study conducted in Southern Saxonia, lead in blood and lead in tap  
5 water were measured for school children from two locations, A and B (Englert *et al.*,  
6 1994). Lead pipes were used in about 50% of their houses. After log-transformation of  
7 both their blood lead levels and their drinking water lead levels, 34% of the variation in  
8 blood lead levels was explained by logWLL in location A (i.e.  $R^2=0.34$  for location A),  
9 and 41% of the variation was explained in location B (i.e.  $R^2=0.41$  for location B) (Table  
10 10). These authors concluded that in this part of Germany, lead exposure through  
11 drinking water was a greater concern than lead paint and other sources, due to the lead  
12 pipes in the water supply which had not yet been removed. Seven years later, after many  
13 lead pipes had been replaced with alternative materials, another study quantified WLLs in  
14 homes of new-born babies in various regions of Southern Saxonia (Zietz, 2001). Overall,  
15 3.1% of the 1434 stagnation samples had lead higher than 10  $\mu\text{g/L}$ . But certain  
16 geographic regions were at higher risk (>5% above 10  $\mu\text{g/L}$ ), and these authors  
17 concluded that the exceptional cases were due to leaching of domestic plumbing and  
18 fittings containing lead (Zietz, 2001).

19  
20 Following a case of lead intoxication by drinking water in Ste-Agathe-des Monts, a  
21 Canadian study demonstrated a link between EBLs and WLLs, as well as presence of  
22 lead service lines (Savard, 1992). Canada did not provide guidance for national corrosion  
23 control programs until 2009 (Health Canada, 2009) and this town still distributed  
24 corrosive water. On the basis of field investigations and 383 blood lead analyses, BLLs  
25 higher than 20  $\mu\text{g/dL}$  were associated with the presence of lead service lines (Yates’ Chi-  
26 square test: 5.85;  $p=0.02$ ) (Savard, 1992). A mathematical model was developed for the  
27 72 citizens for which WLLs were measured (Table 10). Lead concentrations in those  
28 samples were as high as 4200  $\mu\text{g/L}$ . Water consumption was obtained on the basis of a  
29 questionnaire. Using a linear regression between BLL and the estimated lead daily intake,  
30 a correlation coefficient of  $R^2=0.25$  was obtained (Savard, 1992). The water corrosivity  
31 was rapidly identified as the problem (pH as low as 4.8 measured in some houses) and  
32 corrective measures were taken by increasing the pH to 8.4. After less than a month,  
33 WLLs were reduced by more than 90%, and the measured BLLs were significantly  
34 reduced by 24% in less than a year. Work with lead paint or dust mitigation has also  
35 demonstrated that, in some cases, mitigation of the suspected lead hazard only slightly  
36 reduces blood lead, if high levels of lead have been stored in bone (Rust *et al.*, 1999;  
37 Gwiazda *et al.*, 2005).

38  
39 Watt *et al.* (1996) assessed the relationship between tap water lead and maternal blood  
40 lead concentrations in Glasgow, after the water supply was subjected to maximal water  
41 treatment to reduce plumbosolvency. Tap water lead remained the main correlate of  
42 raised maternal blood lead concentrations, accounting for 76% of cases of maternal blood  
43 lead concentrations above 10  $\mu\text{g/dL}$ . The authors concluded that although tap water lead  
44 and maternal blood lead concentrations had fallen substantially since the early 1980s, tap  
45 water lead was still a public health problem in that area, especially for the estimated 13%

1 of infants who were exposed via bottle feeds to tap water lead concentrations exceeding  
2 the WHO guideline of 10 µg/L.

3  
4 Lanphear et al. (2002) assessed the contribution of lead in water versus other sources to  
5 children's blood lead levels during early childhood. Children from 6 until 24 months of  
6 age were monitored in Rochester New York, a community not considered to have lead-  
7 in-water problems according to the EPA LCR. Samples of tap water, house dust, soil and  
8 paint were quantified for lead, with house dust being determined as the main source of  
9 lead exposure. Even so, water lead concentration was also directly associated with blood  
10 lead levels ( $p < 0.001$ ). Children who lived in housing with water lead concentration  
11 greater than 5 µg/L had slightly higher (1.0 µg/dL) blood lead levels than children who  
12 had home water lead levels below 5 µg/L (Lanphear et al. 2002).

13  
14 Taking into account geographic risk factors during an incident of sub-optimal corrosion  
15 control, Edwards et al. (2009) found a strong correlation between the frequency of EBL  
16 and the 90<sup>th</sup> percentile lead in water concentration from 2000-2007 in Washington DC.  
17 In neighborhoods determined to have the greatest frequency of lead pipe and highest lead  
18 concentrations, a correlation was found for children less than 30 months of age (Table  
19 10). Older children, children living in neighborhoods with relatively few lead pipes or  
20 measurements of elevated lead in water, showed lesser impacts. But the youngest  
21 children (< 1.3 years) showed very strong correlations between the incidence of EBL and  
22 the reported 90<sup>th</sup> percentile lead in water concentration. Earlier studies on Washington DC  
23 (Stokes et al., 2004; Guidotti et al., 2007) did not focus on the youngest children or  
24 geographical factors, and saw little or no increased incidence of EBL during the time of  
25 high lead in water.

## 26 27 **Studies that did not find an association between WLLs and BLLs**

28 Many other studies have found little or no relationship between lead in blood and lead in  
29 water. These studies are occasionally cited as if results are contradictory to those  
30 highlighted in the preceding section. That work is critically reviewed herein, in an  
31 attempt to reconcile results that are superficially in conflict, but which are consistent with  
32 bio-kinetic understanding of relationships between lead in water exposure and lead in  
33 blood.

### 34 35 ***Lack of Association between WLL and BLL When Lead in Water was reportedly Low.***

36 There are many areas in the US (and other countries) in which water lead concentrations  
37 are very low. This can occur in situations with modern plumbing which has no lead pipe,  
38 lead solder or leaded brass, and with optimized corrosion control which can dramatically  
39 reduce lead leaching. Some older cities with high incidence of lead pipe and lead solder,  
40 have pipes that are virtually completely lined by scale such as calcium carbonate, which  
41 effectively eliminates contact between the lead-bearing plumbing and the water. In such  
42 circumstances lead in water will not be a dominant, or even a significant contributor, to  
43 overall lead exposure.

44

1 For instance, in a study by Lubin et al. (1984), where water samples were collected in the  
2 homes of 50 children with BLL > 30 µg/dL in Columbus, Ohio, lead in water was always  
3 low (< 10 µg/L). It is believed that the water supply in that study was atypically non-  
4 corrosive (high pH of 9.6 and high hardness of 101 mg/L). Not surprisingly, there was  
5 no correlation between lead in water and lead in blood, even in the presence of lead pipes  
6 at the children's homes. Likewise, a study in Germany (Meyer et al., 1998) in a town  
7 where lead in tap water was extremely low (< 1 µg/L) found no significant association  
8 between lead in domestic water and in blood for children. Another study of children's  
9 BLL in Miami Inner City, Florida (Gasana et al., 2006), also found no association of  
10 BLLs to WLLs (Spearman's rho = 0.03 for flushed water samples and 0.005 for first  
11 draw water samples). Water lead measured in 120 homes was reportedly low (< 15 µg/L),  
12 with the exception of 3 homes. However, correlations between BLL and floor dust (rho =  
13 0.27) and window sill (rho = 0.28) were statistically significant (p < 0.05) (Gasana et al.,  
14 2006).

15  
16 Another important study by Rabinowitz et al. (1985) examined the association of BLLs  
17 of infants in Boston with lead in dust, soil, indoor air, paint and tap water. The authors  
18 found statistically significant correlations of children's BLL at age 24 months with lead  
19 in dust (Spearman's rho = 0.4, P<0.0001), with lead in soil (Spearman's rho = 0.3, P <  
20 0.001), and with lead in paint (Spearman's rho = 0.2, P < 0.01), but not with lead in water  
21 (Spearman's rho = 0.14, not statistically significant). The conclusions of that work  
22 regarding important contributions of dust, soil and paint to BLL are consistent with  
23 expectations. However, analytical limitations in quantification may have masked any  
24 potential contribution of WLL to BLL, if it were present. Specifically, lead in water was  
25 quantified using anodic stripping voltametry. This analytical technique has recently been  
26 shown to accurately measure dissolved Pb<sup>+2</sup>, but to not measure particulate lead or Pb<sup>+4</sup>  
27 levels in water (Cartier et al., 2009). The latter species have recently proved to be present  
28 in drinking water under at least some circumstances (Triantafyllidou et al., 2007), but  
29 were not understood at the time of the Rabinowitz study. Moreover, samples were  
30 allowed to sit unacidified before analysis, which is now recognized to potentially miss  
31 some of the lead present in water (Rabinowitz, 2006). Perhaps, partly because of these  
32 issues, only very low levels of lead (3.7 – 7.3 µg/L) were reported for Boston drinking  
33 water samples (Rabinowitz et al., 1985).

34  
35 To provide a historical perspective for Boston, Potula et al. (1999) found lead in water of  
36 Boston homes as high as 169 µg/L during the same time period. Boston water, which  
37 was linked to lead poisoning via infant formula was reported by Shannon et al. (1982) to  
38 contain 132 µg/L. Even as late as 1996-2000, lead levels in first-draw tap water samples  
39 from Boston were 159 µg/L on average, and as high as 311 µg/L in the worst case for  
40 children with elevated blood lead (State of Massachusetts, 2009). Even flushed water  
41 samples for lead poisoned children in the 2009 data from Massachusetts contained as  
42 high as 146 µg/L lead.

43  
44 ***Lack of Association between WLL and BLL When Lead in Water was reportedly High.***  
45 Some studies have found no association between elevated lead in water and elevated lead  
46 in blood. Key aspects of such studies are critically reviewed herein, especially as they

1 relate to potential limitations described in preceding sections (see Table 10). For  
2 example, Costa et al. (1997) reported that very high water lead levels in a public school in  
3 rural Utah (up to 840 µg/L) did not cause EBLL. In that study, measurements of blood  
4 lead were undertaken for only 40% of students, more than 16 days after notification of  
5 the problem and advice to drink bottled water, during which time lead in blood could  
6 drop, considering its half life of around one month (WHO, 2000). Even though one case  
7 of elevated blood lead was identified, it was dismissed as un-related to water lead (Costa  
8 et al. 1997).

9  
10 A CDC study reported that in 201 cases where home tap water contained more than 300  
11 µg/L of lead in Washington DC, none of the individuals were found to suffer from EBLL  
12 (Stokes et al., 2004). Another study on the same topic cited the same data, and did not  
13 find an association between elevated lead in water and lead in blood, concluding that  
14 “there appears to have been no identifiable public health impact from the elevation of  
15 lead in drinking water in Washington DC, in 2003 and 2004” (Guidotti et al., 2007).  
16 Neither study focused on infants, who are most vulnerable to harm from lead in water. In  
17 addition, both studies lumped all the blood lead data for Washington, DC together, an  
18 approach which masked disparities among different neighborhoods (Edwards et al.,  
19 2009). Finally, as mentioned earlier, virtually no residents had been consuming tap water  
20 for months prior to having their blood lead drawn, rendering the data useless for  
21 assessing impacts of lead in water on lead in blood (Edwards et. al., 2009; CDC, 2010b).  
22 The “no-harm” conclusion of Guidotti et al. (2007) has since been removed (Errata in  
23 Environmental Health Perspectives, 2009).

#### 24 **Studies That Did Not Measure Lead in Water at Homes**

25  
26 Some researchers attempted to assess the contribution of lead in water to lead in blood,  
27 without measuring lead in tap water at homes. For example, studies occasionally relied  
28 on qualitative data obtained from questionnaires regarding consumers’ water  
29 consumption habits (tap water versus filtered or bottled water), and/or knowledge  
30 regarding the presence of lead pipes in consumers’ home plumbing. Other studies relied  
31 on lead-in-water measurements obtained from the distribution system and not home taps,  
32 which can result in overlooking tap water as a potentially important source.

33  
34 For example, a broad Cincinnati study aimed to investigate different lead sources and  
35 factors which result in excessive intake for children in urban settings (Bornschein et al.,  
36 1985; Clark et al., 1985). Blood lead levels were systematically monitored from birth  
37 through 5 years of age and a broad range of lead sources in the children’s environment  
38 were accounted for, including painted surfaces and dust, soil samples in outside playing  
39 area, street dirt, and any suspicious items which the children were mouthing. Water  
40 samples were not collected in this otherwise very thorough and definitive study. Instead,  
41 sampling data collected by the water utility from the distribution system, before the water  
42 even enters the service line where lead hazards are introduced (see Figure 1), were cited  
43 as having lead concentrations < 6 µg/L (Clark et al., 1985). Exposure from water was  
44 thus deemed to be insignificant when in fact, samples were never collected in a manner  
45 that would allow risks to be quantified if they were present. Historical data from Greater

1 Cincinnati Water Works suggest that even in recent years, with modern corrosion control,  
2 some Cincinnati schools had tap water lead levels above 15 µg/L, while some homes  
3 tested at 180 µg/L after partial lead pipe replacements (DeMarco, 2004).

4  
5 A study in Northern France (Leroyer et al., 2000) showed that BLLs doubled for children  
6 who reported consuming tap water in homes with lead plumbing identified under the  
7 kitchen sink. In cases where lead pipes were not visible under the kitchen sink, children  
8 drinking tap water still had significantly higher BLLs compared to those consuming  
9 bottled water (Leroyer et al., 2000). The authors (Leroyer et al., 2000) qualified their  
10 conclusions by suggesting that water sampling should be conducted to more carefully  
11 assess their findings, which relied on visual identification of lead plumbing and  
12 qualitative answers to a questionnaire.

### 13 **Synthesis of studies on the association between lead in water and in blood**

14 Rigorous scientific studies prior to implementation of modern corrosion control provided  
15 strong links between elevated lead in water and elevated blood lead (i.e., greater than 10  
16 µg/dL) of exposed populations. As would be expected based on current understanding of  
17 dietary intake and hand-mouth behavior relative to significance of lead sources, impacts  
18 of elevated lead in water on lead in blood become more significant the younger the child,  
19 with especially high risks for children consuming reconstituted infant formula. The work  
20 of Lacey et al. (1985) and Ryu et al. (1983) exemplify rigorously controlled studies that  
21 are unlikely to be improved upon in the near future, and which served as the basis for the  
22 US EPA LCR and models predicting BLL developed by the US EPA.

23  
24 Two landmark multimedia US studies (Bornschein et al., 1985 and Rabinowitz et al.,  
25 1985), did not find any association between lead in water and in blood for children in  
26 Cincinnati and Boston. The strong relationships established in that research between lead  
27 in paint, dust and soil and children's blood are not disputed, but each study had  
28 limitations or gaps in quantifying lead in water risks.

29  
30 More recent studies in Canada, Germany, the UK and the US, sometimes found strong  
31 associations between WLLs and BLLs, and sometimes not. These studies reflect marked  
32 differences in the extent of lead in water exposure based on plumbing materials,  
33 corrosivity of the water, and other nuances of exposure. Some recent work by the CDC  
34 and others that concluded very high lead in water (> 300 µg/L ) did not impact incidence  
35 of EBL in an exposed population has been re-analyzed, corrected or clarified (Edwards et  
36 al., 2009; Errata in Environmental Health Perspectives, 2009, CDC, 2010b; Edwards,  
37 2010; US Congressional report, 2010). That work is no longer inconsistent with decades  
38 of prior research. Other work has demonstrated strong links between lead in water and  
39 lead in blood even at much lower levels of lead in water exposure, in systems conducting  
40 "optimized corrosion control" or its equivalent (Lanphear et al., 2002; Englert et al.,  
41 1994; Fertmann et al., 2004).

1 **VIII. SUMMARY AND CONCLUSIONS**

2  
3 As efforts shift from addressing pervasive lead sources that elevate the blood lead of  
4 large percentages of the population, to more isolated individual cases requiring  
5 exceptional attention, it will be necessary to more carefully consider lead in water as a  
6 potential source.

7  
8 Although routine blood lead monitoring and environmental assessments are not designed  
9 to detect lead in water hazards when present, several recent cases of elevated blood lead  
10 in the US and other countries have been attributed to lead-contaminated drinking water.  
11 Existing US regulations/guidelines have not eliminated lead in water hazards in systems  
12 served by public water supplies, schools, daycares and privately owned homes.

13  
14 Lead in drinking water originates from lead-bearing plumbing materials, which undergo  
15 corrosion reactions, and may severely contaminate the water supply. Contrary to popular  
16 belief that lead in water problems invariably decrease as water systems age and rust/scale  
17 develops on pipes, problems with sporadic detachment of rust/scale on lead-bearing  
18 plumbing might create acute human health risks that are hard to detect and link to  
19 elevations of lead in blood. Up to 81 million US homes are estimated to be at potential  
20 risk due to the presence of lead pipe and lead solder, and even new homes can  
21 occasionally experience high lead from brass/bronze plumbing. The occurrence of  
22 particulate lead in US drinking water has not been adequately examined, but case studies  
23 suggest that the highest doses of lead are associated with the presence of particulate (and  
24 not dissolved) lead in tap water.

25  
26 When water lead measurements are not available at "high risk" taps, or when they fail to  
27 quantify the actual lead content of drinking water, correlations of water lead with health  
28 risks may be missed. A strong association between lead in water and lead in blood has  
29 been documented through decades of prior scientific research. Epidemiological studies in  
30 the US, the UK, Germany, France, and Canada indicate that elevated lead in water can  
31 occasionally be the dominant, or a major contributor, to elevated blood lead. Re-  
32 evaluation of the public health risk from lead in water, with emphasis on particulate lead  
33 and sensitive sub-populations, is timely considering forthcoming revisions to the LCR  
34 and acknowledged deficiencies in addressing lead in school drinking water.

35 **IX. RESEARCH NEEDS**

36  
37 This literature review highlighted the need for additional research on lead occurrence in  
38 tap water and associated public health risks. Specifically, the occurrence of lead in  
39 drinking water at US schools needs to be systematically monitored, using sampling  
40 protocols that will allow identification of the source(s) of potential problems and  
41 development of concise remedial actions. Detailed case studies on lead-in-school water  
42 could then be synthesized, and serve as a guide for schools that encounter similar  
43 problems in the future.  
44

1 The effects of sampling protocol (e.g., flow rate, cold versus hot water) and sample  
2 handling (e.g. sample preservation and holding time) on lead detection need to be  
3 evaluated for all situations including schools, homes and other buildings. Subtle  
4 differences in sample collection procedures can either detect or completely miss lead  
5 spikes, especially when problems with particulate lead in water are important. The  
6 occurrence of particulate lead spikes in US drinking water needs to be better  
7 characterized, because it may result in intermittent exposures of acute health concern,  
8 which can easily go undetected. Acute health effects from lead in water, concentration of  
9 lead in food, and potential exposure to elevated lead from hot water deserve explicit  
10 consideration.

11  
12 Old lead service lines are a major contributor to lead levels at the tap, when they are  
13 present. Partial replacements of lead service lines in response to provisions of the LCR,  
14 as a means of reducing lead-in-water exposure, require re-evaluation in light of  
15 preliminary data showing short- and long-term problems with lead spikes and increased  
16 risks of elevated blood lead in children. Laboratory studies quantifying the long-term  
17 impacts in a range of waters, as well as the cost: benefit of the procedure, are necessary.  
18 Likewise, evaluation of impacts from newly installed leaded-brass plumbing devices is  
19 also needed.

20  
21 Past approaches in modeling health impacts from elevated lead in water, based on  
22 prediction of the geometric mean BLL, was useful when considering impacts on  
23 populations. But as society shifts its concern to tracking and addressing individual cases  
24 of childhood lead poisoning, modeling approaches need to consider and predict impacts  
25 on susceptible individuals exposed to the highest sampled lead in water concentrations.

26

## 27 **ACKNOWLEDGEMENTS**

28

29 The authors acknowledge the financial support of the National Science Foundation under  
30 grant CBET-0933246. Opinions and findings expressed herein are those of the authors  
31 and do not necessarily reflect the views of the National Science Foundation. The authors  
32 would also like to thank the anonymous reviewers for their valuable comments.

33

## **REFERENCES**

34

35 Agency for Toxic Substances and Disease Registry (ATSDR). Lead Toxicity: What Are  
36 the U.S. Standards for Lead Levels? 2007. Accessed on 1/15/2010 at  
37 [http://www.atsdr.cdc.gov/csem/lead/pb\\_standards2.html](http://www.atsdr.cdc.gov/csem/lead/pb_standards2.html)

38 Bach D. 2005. Schools' drinking water still fails lead test. *Seattle Post-Intelligencer*,  
39 Wednesday July 20. Accessed 6/9/08 at  
40 [http://seattlepi.nwsourc.com/local/233287\\_lead20.html](http://seattlepi.nwsourc.com/local/233287_lead20.html)

41 Baxter, M.J.; Burrell, J.A.; Crews, H.M.; Smith A. and Massey R.C., Lead contamination  
42 during domestic preparation and cooking of potatoes and leaching of bone-derived  
43 lead on roasting, marinating and boiling beef, *Food Additives and Contaminants*  
44 9:3:225, 1992.

- 1 Biesecker, M. Lead found in schools' water. *The News and Observer*, Fri, Aug 25, 2006.  
2 Accessed on 15/7/2010 at [http://www.newsobserver.com/2006/08/25/53632/lead-](http://www.newsobserver.com/2006/08/25/53632/lead-found-in-schools-water.html#storylink=misearch)  
3 [found-in-schools-water.html#storylink=misearch](http://www.newsobserver.com/2006/08/25/53632/lead-found-in-schools-water.html#storylink=misearch)
- 4 Bisogni Jr., J. J., Nassar, I. S., and Menegaux, A. M., Effect of Calcium on Lead in Soft-  
5 Water Distribution Systems. *ASCE Journal of Environmental Engineering*, 126(5),  
6 475-478, 2000.
- 7 Blette, V. Drinking water public right-to-know requirements in the United States.  
8 *Journal of Water and Health* 6(S1):s43-s51, 2008.
- 9 Bolduc, G. Lakehurst Acres residents' tests indicate lead in blood. *Kennebec Journal*.  
10 September 20, 2006.
- 11 Bolduc, G. Lead levels watched. *Kennebec Journal*. 06 Jun, 2010.  
12 [http://findarticles.com/p/news-articles/kennebec-journal/mi\\_8137/is\\_20060909/lead-](http://findarticles.com/p/news-articles/kennebec-journal/mi_8137/is_20060909/lead-levels-watched/ai_n50615517/)  
13 [levels-watched/ai\\_n50615517/](http://findarticles.com/p/news-articles/kennebec-journal/mi_8137/is_20060909/lead-levels-watched/ai_n50615517/)
- 14 Bonnefoy, X., Huel, G., Gueguen, R. Variation of the Blood Lead Level as a Result of  
15 Lead Contamination of the Subjects Drinking Water, *Water Res.* 19, 1299-1303, 1985.
- 16 Bornschein, R. L., Hammond, P. B., Dietrich, K. N., Succop P., Krafft, K., Clark S.,  
17 Berger, O., Pearson, D., and Que Hee, S.. The Cincinnati prospective study of low-  
18 level lead exposure and its effects on child development: protocol and status report,  
19 *Environmental Research* 38, 4-18, 1985.
- 20 Boyd G.R., Pierson G.L., Kirmeyer G.J., Britton M.D, English R.J. Lead Release from  
21 new end-use plumbing components in Seattle public Schools. *Journal AWWA*, 100(3):  
22 105-114, 2008a.
- 23 Boyd G.R., Pierson G.L., Kirmeyer G.J., English R.J. Lead variability testing in Seattle  
24 public schools. *Journal AWWA*, 100(2):53-64, 2008b.
- 25 Bryant, S.D.. Lead-Contaminated Drinking Water in the Public Schools of Philadelphia.  
26 *Journal of Toxicology Clinical Toxicology*, 42(3):287-294, 2004.
- 27 Burke, G.. AP Impact: School Drinking Water Contains Toxins, *Associated Press*,  
28 September 25, 2009, Accessed on 7/17/2010 at  
29 [http://www.thefreelibrary.com/AP+IMPACT%3a+School+drinking+water+contains+t](http://www.thefreelibrary.com/AP+IMPACT%3a+School+drinking+water+contains+toxins-a01612006294)  
30 [oxins-a01612006294](http://www.thefreelibrary.com/AP+IMPACT%3a+School+drinking+water+contains+toxins-a01612006294)
- 31 Burney, M. and Dwight, O. *The Philadelphia Inquirer*, Thursday March 13. Schools must  
32 surrender lead reports. South Jersey; pg. B01, 2003.
- 33 California Environmental Protection Agency (Cal/EPA), 1997. Public Health Goal for  
34 lead in Drinking Water. Accessed on 7/17, 2010 at  
35 [http://oehha.ca.gov/water/phg/pdf/lead\\_c.pdf](http://oehha.ca.gov/water/phg/pdf/lead_c.pdf)
- 36 Cartier, C, Prevost, M., Shokoufeh, N., Pirog, M. A Rapid Method for Detection of Lead  
37 Service Lines. Water Quality Technology Conference, Seattle, 2009.
- 38 CDC. Blood lead levels in residents of homes with elevated lead in tap water-District of  
39 Columbia, 2004. *Morb. Mort. Weekly Rep.* 53, 268-270, 2004.
- 40 CDC. Managing elevated blood lead levels among young children: Recommendations  
41 from the Advisory Committee on Childhood Lead Poisoning Prevention. Atlanta: US  
42 Department of Health and Human Services; 2002. Accessed October 22 2009 at  
43 [http://www.cdc.gov/nceh/lead/CaseManagement/caseManage\\_main.htm](http://www.cdc.gov/nceh/lead/CaseManagement/caseManage_main.htm)
- 44 Centers for Disease Control and Prevention (CDC). 2006. Death of a child after  
45 ingestion of a Metallic Charm - Minnesota, 2006. *Morbidity and Mortality Weekly*  
46 *Report*, March 23.

- 1 Centers for Disease Control and Prevention. 2004. Brief Report: Lead Poisoning from  
2 Ingestion of a Toy Necklace -Oregon, 2003. *Morbidity and Mortality Weekly Report*  
3 June 18, 2004.
- 4 Centers for Disease Control and Prevention. Preventing Lead Poisoning in Young  
5 Children. Atlanta: CDC, 2005.
- 6 CDC. Lead - Tips - Sources of Lead - Water. Accessed at  
7 <http://www.cdc.gov/nceh/lead/tips/water.htm>, 5/20, 2010a.
- 8 CDC. Notice to Readers: Limitations Inherent to a Cross-Sectional Assessment of Blood  
9 Lead Levels Among Persons Living in Homes with High Levels of Lead in Drinking  
10 Water. *Morbidity and Mortality Weekly Report (MMWR)*, 59(24), 751, 2010b.  
11 Accessed on 7/19/2010 at  
12 <http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5924a6.htm>
- 13 CDC. Lead-Contaminated Drinking Water in Bulk-Water Storage Tanks-Arizona and  
14 California, 1993, *Morbidity & Mortality Weekly Report*, Epidemiologic Notes and  
15 Reports, 43:October 21, 1994
- 16 Chambers V.K. and Hitchmough S.M., 1992. Economics of lead pipe replacement  
17 (TMU. 9030). Final report to the Department of the Environment, DOE 2956/1.
- 18 City of Baltimore. 2007. Baltimore City Public Schools' CEO Announces System-wide  
19 Shift to Bottled Drinking Water. Press release, 7 Nov. Baltimore, Maryland.
- 20 Clark, C., Bornschein, R., Succop, P., Que Hee, S., Hammond, P., Peace, B. Condition  
21 and type of housing as an indicator of potential environmental lead exposure and  
22 pediatric blood lead levels, *Environmental Research* 38(1), 46-53, 1985.
- 23 Cooper, M. Parent who discovered high lead in water at Seattle school. Personal  
24 communication on 7/13, 2008.
- 25 Copeland, L., 2004. Blood and Water: The Long Search for the Source of a Baby's Lead  
26 Poisoning. *Washington Post*. Accessed 3/20/2006 at [http://washingtonpost.com/wp-](http://washingtonpost.com/wp-dyn/articles/A28828-2004Mar3.html)  
27 [dyn/articles/A28828-2004Mar3.html](http://washingtonpost.com/wp-dyn/articles/A28828-2004Mar3.html)
- 28 Cosgrove, E.V.; Brown, M. J.; Madigan, P.; McNulty, P.; Okonski, L.; Schmidt, J.  
29 Childhood lead poisoning: Case study traces source to drinking water. *J. Environ.*  
30 *Health*. 52, 346-349, 1989.
- 31 Costa, R.A., Nuttall, K.L. and Shaffer, J.B. et al. Suspected lead poisoning in a public  
32 school, *Ann. Clin. Lab. Sci.* 27, 413-417, 1997.
- 33 DeMarco, J. 2004. A Partial Lead Service Line Replacement Program! Does It Make  
34 Sense? US EPA Workshop on Lead Service Replacement. October 26-27, 2004.
- 35 De Mora, S. J., Harrison, R. M., and Wilson, S. J. The Effect of Water Treatment on the  
36 Speciation and Concentration of Lead in Domestic Tap Water Derived from a Soft  
37 Upland Source. *Water Res.*, 21(1), 83-94, 1987.
- 38 De Rosa, S., Williams, S.M. Particulate Lead in Water Supplies (TMU 9024). Final  
39 Report to the Department of the Environment. 1992. Water Research Center,  
40 Swindon, UK.
- 41 DC WASA (District of Columbia Water and Sewer Authority). Response to questions  
42 from Carol Leonnig of the Washington Post, in her e-mail dated 3/17/08.
- 43 Edwards, D. 2007. Teacher discovers water tainted by lead at West Davidson High  
44 School. *The Dispatch*. Saturday, March 31. Accessed 15/7/2010 at [http://www.the-](http://www.the-dispatch.com/apps/pbcs.dll/article?AID=/20070331/NEWS/703310341/1005/news)  
45 [dispatch.com/apps/pbcs.dll/article?AID=/20070331/NEWS/703310341/1005/news](http://www.the-dispatch.com/apps/pbcs.dll/article?AID=/20070331/NEWS/703310341/1005/news)

1 Edwards, M., Dudi, A. Role of chlorine and chloramine in corrosion of lead-bearing  
2 plumbing materials. *Journal American Water Works Association* 96(10), 69-81, 2004.  
3 Edwards, M., Scardina, P., GV Loganathan, D Bosch, and S Dwyer. 2007. Non-  
4 Uniform Corrosion in Copper Piping—Assessment, AwwaRF Report #91217.  
5 Edwards, M., Scardina, P., Parks, J. 2006. Lead in Durham Water: Site Visit Report.  
6 June 27.  
7 Edwards, M. AEESP Scientists Luncheon. Lead Copper Rule Sampling and Public  
8 Health Goals for Lead. October 31, 2005.  
9 Edwards, M. Testimony before the US House of Representatives Committee on Science  
10 and Technology, 111<sup>th</sup> Congress on *Preventing Harm—Protecting Health: Reforming*  
11 *CDC's Environmental Public Health Practices*, 5/17, 2010.  
12 Edwards, M., Triantafyllidou, S. and Best, D. Elevated Blood Lead in Young Children  
13 Due to Lead-Contaminated Drinking Water: Washington, DC, 2001–2004,  
14 *Environmental Science and Technology*, 43:5, 1618–1623, March 2009  
15 Elfland, C., Scardina, P., and M. Edwards. Lead Contaminated Water from Brass  
16 Plumbing Devices in New Buildings . Accepted for publication in JAWWA, 2010  
17 Elwood, P.C. and Toothill, C. Greater contribution to blood lead from water than from  
18 air, *Nature* 310, 138-411, 1985.  
19 Englert, H., Horing, H. Lead concentration in tap water and in blood of selected  
20 schoolchildren in southern Saxonia, *Toxicol Lett.* 72, 325-331, 1994.  
21 Environmental Health Perspectives. Errata: Elevated Lead in Drinking Water in  
22 Washington, DC, 2003-2004: The Public Health Response. 117:8, p A 342, 2009.  
23 Fadrowski, J. J., Navas-Acien, A., Tellez-Plaza, M., Guallar, E., Weaver, V. M., Furth, S.  
24 L. Blood Lead Level and Kidney Function in US Adolescents: The Third National  
25 Health and Nutrition Examination Survey. *Arch. Intern. Med.* 170(1), 75-82, 2010.  
26 Fertmann, R., Hentschel, S., Dengler, D., Janssen, U., and Lommel, A. Lead exposure by  
27 drinking water: an epidemiological study in Hamburg, Germany, *International Journal*  
28 *of Hygiene and Environmental Health* 207, 235–244, 2004.  
29 Fitzgerald S., 2000. District: Unsafe Lead Levels found in 20% of Water Outlets in  
30 Testing Water in 289 older school buildings. The district knew of the problem years  
31 ago, an EPA official testified. *The Philadelphia Inquirer*, Tuesday November 21,  
32 Page B01.  
33 Freking, K. EPA unveils plan for safe drinking water. The Daily Reporter. Accessed on  
34 12/11, 2009 at [http://dailyreporter.com/blog/2009/12/09/epa-unveils-plan-for-safe-](http://dailyreporter.com/blog/2009/12/09/epa-unveils-plan-for-safe-drinking-water/)  
35 [drinking-water/](http://dailyreporter.com/blog/2009/12/09/epa-unveils-plan-for-safe-drinking-water/)  
36 Frumkin, H. Important update: lead-based water lines. *CDC's Healthy Homes and Lead*  
37 *Poisoning Prevention Branch*, 2010. Accessed on 1/15/2010 at  
38 <http://www.cdc.gov/nceh/lead/waterlines.htm>  
39 Galke, W., Dixon, S., McLaine, P., Wilson, J., Ashley, P. US Department of Housing and  
40 Urban Development. Study of HUDs Risk Assessment Methodology in three U.S.  
41 Communities. June 30, 2006. Accessed on 7/10/2010 at  
42 <http://www.nchh.org/LinkClick.aspx?fileticket=HZUenslvU/0=&tabid=217>  
43 Gardner, C. Compliance Section Manager, Maine Drinking Water Program, Personal  
44 Communication on 12/27/2006.

- 1 Gasana, J., Hlaing, W. M., Siegel, K. A., Chamorro, A., Niyonsenga, T. Blood Lead  
2 Levels in Children and Environmental Lead Contamination in Miami Inner City,  
3 Florida. *Int. J. Environ. Res. Public Health* 3(3), 228-234, 2006.
- 4 Gerwin, S. Washington Suburban Sanitary Commission. 2004. A Water System's  
5 Experience. *Lead in Drinking Water in Schools and Child Care Facilities Meeting*  
6 *Summary*. December 7. Accessed 5/10/2008 at  
7 [http://www.epa.gov/ogwdw/lcrmr/pdfs/summary\\_lcmr\\_review\\_school\\_12-07-04.pdf](http://www.epa.gov/ogwdw/lcrmr/pdfs/summary_lcmr_review_school_12-07-04.pdf)
- 8 Goss, C. Lead Ban Surveillance Project. Pennsylvania Department of Environmental  
9 Protection, Bureau of Water Standards and Facility Regulation Safe Drinking Water  
10 Program. 2008. Accessed on 1/15/2010 at  
11 [http://www.healthyhomestraining.org/Codes/State\\_Codes/PA\\_Products\\_Lead\\_Plumbi](http://www.healthyhomestraining.org/Codes/State_Codes/PA_Products_Lead_Plumbi)  
12 [ng\\_8-14-09.pdf](http://www.healthyhomestraining.org/Codes/State_Codes/PA_Products_Lead_Plumbi)
- 13 Greenwire. Lead: Schools Adopt Varying Guidelines to Reduce Levels in Drinking  
14 Water. Section Wastes & Hazardous Substances. Vol. 10 No. 9, July 27, 2004.
- 15 Grover, J. Investigative reporter for KNBC. Los Angeles Public Schools Lead-in-Water  
16 Problem. Personal communication, July 8, 2008a.
- 17 Grover, J. School Water. Channel 4 News Extra. KNBC. Los Angeles. 27 Apr, 2008b.
- 18 Grover, J. LAUSD Outlines Plan. Contaminated Water: Expensive Fix. KNBC. Los  
19 Angeles. 22 May, 2008c.
- 20 Guidotti, T.L.; Calhoun, T., John, O., Davies-Cole, J.O., Knuckles, M.E., Stokes L.;  
21 Glymph, C.; Lum, G.; Moses M.S.; Goldsmith, D.F.; Ragain, L. Elevated Lead in  
22 Drinking Water in Washington DC, 2003-2004: The Public Health Response, *Environ.*  
23 *Health Perspect.* 115, 695-701, 2007.
- 24 Gulson, B. L., James, M., Giblin, A. M., Sheehan, A. and Mitchell, P. Maintenance of  
25 elevated lead levels in drinking water from occasional use and potential impact on  
26 blood leads in children. *Science of the Total Environment* 205(2-3), 271-275, 1997.
- 27 Hayes, C. R. and Skubala, N. D. Is there still a problem with lead in drinking water in  
28 the European Union? *Journal of Water and Health* 07(4), 569-580, 2009.
- 29 Gwiazda, R.; Campbell, C.; Smith, D. A Noninvasive Isotopic Approach to Estimate the  
30 Bone Lead Contribution to Blood in Children: Implications for Assessing the Efficacy  
31 of Lead Abatement. *Environmental Health Perspectives* 113(1), 104-110, 2005.
- 32 Health Canada, 1992. Guidelines for Canadian drinking water quality. Technical  
33 document on lead. Accessed on 3/6/2010 at [http://www.hc-sc.gc.ca/ewh-](http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/water-eau/lead/lead-plomb-eng.pdf)  
34 [semt/alt\\_formats/hecs-sesc/pdf/pubs/water-eau/lead/lead-plomb-eng.pdf](http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/water-eau/lead/lead-plomb-eng.pdf)
- 35 Health Canada, 2009. Guidance on Controlling Corrosion in Drinking Water  
36 Distribution Systems. Water, Air and Climate Change Bureau, Healthy Environments  
37 and Consumer Safety Branch, Health Canada, Ottawa, Ontario. (Catalogue No. H128-  
38 1/09-595E).
- 39 Heard, M.J., Chamberlain, A.C. and Sherlock, J.C.. Uptake of lead by humans and effect  
40 of minerals and food. *Science of The Total Environment* 30, 245-253, 1983.
- 41 HDR Engineering. An Analysis of the Correlation between Lead Released from  
42 Galvanized Iron Piping and the Contents of Lead in Drinking Water. Final Report  
43 September 11, 2009. Accessed on 1/15/2010 at  
44 <http://www.dcwasa.com/news/listings/documents/2009-09->  
45 [11%20Final%20Project%20Report.pdf](http://www.dcwasa.com/news/listings/documents/2009-09-)

- 1 Hulsmann, A. D., Particulate Lead in Water Supplies. *Journal of the Institute of Water*  
2 *and Environmental Management*, 4(1), 19-25, 1990.
- 3 Intertox Inc, 2005. Lead in Seattle Public Schools' Drinking Water: Technical Document  
4 prepared for Seattle Public Schools. March 3.
- 5 Jacobs, DE. Lead-based paint as a major source of childhood lead poisoning: a review of  
6 the evidence. In: Lead in Paint, Soil and Dust: Health Risks, Exposure Studies, Control  
7 Measures and Quality Assurance (Beard ME, Iske SDA, eds). Philadelphia:American  
8 Society for Testing and Materials, 175-187, 1995.
- 9 James, H.M., Hilburn, M.E., Blair, J.A. Effects of Meals and Meal Times on Uptake of  
10 Lead from the Gastrointestinal Tract in Humans. *Human & Experimental Toxicology*  
11 4(4), 401-407, 1985.
- 12 Jusko, T. A.; Henderson, C. R.; Lanphear, B. P.; Cory-Slechta, D. A.; Parsons, P. J.;  
13 Canfield, R. L., Blood lead concentrations < 10 µg/dL and child intelligence at 6 years  
14 of age. *Environmental Health Perspectives* 116(2), 243-248, 2008.
- 15 Kalra, V., Gulati, S., Chitrlekha, K.T., et al. Plumbism-a mimicker of common  
16 childhood symptoms, *Indian J Pediatr.* 67(2), 81-86, 2000.
- 17 Karalekas P.C. Jr, Craun G.F., Hammonds A.F., Ryan C.R., and D.J. Dorth, Lead and  
18 other trace metals in drinking water in the Boston Metropolitan area, *J. New Engl.*  
19 *Water Wks Ass.* 90, 150-172, 1976.
- 20 Lacey, R., Moore, M., Richards, W. Lead in water, infant diet and blood: The Glasgow  
21 duplicate diet study 1979-1980, *Sci. Total. Environ.* 41, 235-257, 1985.
- 22 Lambrinidou Y. and Edwards M. Lead in DC Public School Drinking Water: Filter  
23 Monitoring and Follow Up Testing, Preliminary Report, Prepared for District of  
24 Columbia Public Schools, 24 July, 2008.
- 25 Lambrinidou, Y., Triantafyllidou, S., Edwards, M. Failing Our Children: Lead in US  
26 School Drinking Water, *New Solutions* 20(1): 25-47, 2010.
- 27 Lambrinidou, Y. Personal communication on 12/10, 2008.
- 28 Lanphear, B.P., Hornung, R., Ho, M., Howard, C.R., Eberley, S., and Knauf, K.  
29 Environmental lead exposure during early childhood, *Journal of Pediatrics* 140: 40-  
30 47, 2002.
- 31 Leonnig. C., 2009. More D.C. Kids Had Elevated Lead Than Stated. *Washington Post*,  
32 Tuesday August 4. Accessed on 01/18/2010 at [http://www.washingtonpost.com/wp-](http://www.washingtonpost.com/wp-dyn/content/story/2009/02/11/ST2009021100308.html)  
33 [dyn/content/story/2009/02/11/ST2009021100308.html](http://www.washingtonpost.com/wp-dyn/content/story/2009/02/11/ST2009021100308.html)
- 34 Leonnig. C., 2004. Lead Levels in Water Misrepresented Across U.S. Utilities  
35 Manipulate or Withhold Test Results to Ward Off Regulators. *Washington Post*,  
36 Tuesday, October 5, 2004; Page A01. Accessed on 03/20/2009 at  
37 [http://www.washingtonpost.com/wp-](http://www.washingtonpost.com/wp-dyn/content/story/2009/02/11/ST2009021100308.html)  
38 [dyn/content/story/2009/02/11/ST2009021100308.html](http://www.washingtonpost.com/wp-dyn/content/story/2009/02/11/ST2009021100308.html)
- 39 Leroyer, A., Nisse, C., Hemon, D., Gruchociak, A., Salomez, J-L, and Haguenoer, J-M,  
40 Environmental Lead Exposure in a Population of Children in Northern France: Factors  
41 Affecting Lead Burden. *American Journal of Industrial Medicine*, 38, 281-289, 2000.
- 42 Levallois P., Gingras, S., Caron, M., and Phaneuf, D. Drinking water intake by infants  
43 living in rural Quebec (Canada). *Science of The Total Environment*, 397(1-3), 82-85,  
44 2008.
- 45 Levin, R.; Brown, M. J.; Kashtock, M. E.; Jacobs, D. E.; Whelan, E. A.; Rodman, J.;  
46 Schock, M. R.; Padilla, A.; Sinks, T., Lead exposures in US children, 2008:

1 Implications for prevention. *Environmental Health Perspectives* 116(10), 1285-1293,  
2 2008

3 Linakis, J.G., Anderson, A.C., Pueschel, S.M. Screening for Lead Poisoning. In Lead  
4 poisoning in childhood, 1996, P. Brookes Pub. Co. (Baltimore). Edited by Siegfried  
5 M. Pueschel, James G. Linakis, Angela C. Anderson, 1996.

6 Little, P., Fleming, R.G., Heard, M.J., Uptake of Lead by Vegetable Foodstuffs During  
7 Cooking, *Sci. Tot. Environ.* 17:2:111, 1981.

8 Lockitch, G., Berry, B., Roland, E., et al. Seizures in a 10-week-old infant: lead  
9 poisoning from an unexpected source. *Canadian Medical Association Journal* 145,  
10 1465-68, 1991.

11 Loghman-Adham, M. Renal Effects of Environmental and Occupational Lead Exposure,  
12 *Environ. Health Perspect.*, 105(9), 928-938, 1997.

13 Lubin, A.H., Signs, S.A., Caffo, A. Tapwater lead in homes of children with undue body  
14 lead burden, *The Ohio State Medical Journal* 80(7), 547-551, 1984.

15 Macintyre, C., Fulton, M., Hepburn, W., Yang, S., Raab, G., Davis, S., Heap, M., Halls, D.  
16 and Fell, G. Changes in blood lead and water lead in Edinburgh. An eight year follow-  
17 up to the Edinburgh lead study, *Environmental Geochemistry and Health*, 20(3), 1998.

18 Maes, E. F.; Swygert, L. A.; Paschal, D. C.; Anderson, B. S. (1991). The contribution of  
19 lead in drinking water to levels of blood lead. I. A cross-sectional study.

20 Mahaffey, K. R. (1977) Quantities of lead producing health effects in humans: sources  
21 and bioavailability, *Environ. Health Persp.*, 19, 285-295.

22 Marcus, W.L. Lead Health Effects in Drinking Water. *Toxicol Ind Health.* 1986  
23 Dec;2(4):363-407.

24 McCafferty, P., Schulz, R. and D'Ercole R. Lead contamination in Perth drinking water,  
25 *Chemistry in Australia*, pp 21-22, 1995.

26 McNeill, L. S.; Edwards, M. Importance of Pb and Cu particulate species for corrosion  
27 control, *Journal of Environmental Engineering-ASCE* 130(2), 136-144, 2004.

28 Mesch, U., Lowenthal, R.M., Coleman, D. Lead Poisoning Masquerading as Chronic  
29 Fatigue Syndrome, *The Lancet*, vol. 347, No 9009. April 27, 1996.

30 Meyer, I, Heinrich, J., Trepka, M.J., Krause, C., Schulz, C., Meyer, E., Lippold, U. The  
31 effect of lead in tap water on blood lead in children in a smelter town, *Sci Total*  
32 *Environ.* 209(2-3), 255-71, 1998.

33 Mielke, H. W., and P. L. Reagan. Soil is an important pathway of human lead exposure.  
34 *Environmental Health Perspectives* 106 (Suppl. 1):217-229, 1998.

35 Montgomery County Public Schools. Updated Analysis of Drinking Water Samples, Oct  
36 22/2004. Accessed 5/10/2008 at  
37 [http://www.montgomeryschoolsmd.org/departments/maintenance/leadinformation/doc](http://www.montgomeryschoolsmd.org/departments/maintenance/leadinformation/docs/WaterAnalysisList10-11.pdf)  
38 [s/WaterAnalysisList10-11.pdf](http://www.montgomeryschoolsmd.org/departments/maintenance/leadinformation/docs/WaterAnalysisList10-11.pdf)

39 Montgomery County Public Schools. Schools Remediation Status, April 11 2007.  
40 Accessed 5/10/2008 at  
41 <http://www.montgomeryschoolsmd.org/departments/maintenance/leadinformation/rem>  
42 [ediationschedule.pdf](http://www.montgomeryschoolsmd.org/departments/maintenance/leadinformation/rem)

43 Moore, M., 1983. Lead Exposure and Water Plumbosolvency. In Lead Versus Health:  
44 Sources and Effects of Low Level Lead Exposure (A Wiley medical publication).  
45 Edited by M. Rutter and R. Russel Jones, Copyright 1983 John Wiley and Sons Ltd.

- 1 Moore, M.R., Richards, W.N., Sherlock, J.G. Successful abatement of lead exposure  
2 from water supplies in the west of Scotland, *Environ. Res.* 38, 67-76, 1985.
- 3 National Research Council Board on Environmental Studies and Toxicology,. Measuring  
4 Lead Exposure in Infants, Children, and Other Sensitive Populations. National  
5 Academy Press, Washington DC, 1993
- 6 National Geographic Magazine. Lead Helps to Guard Your Health (advertisement of the  
7 National Lead Company), Volume 44, 1923.
- 8 Needleman, H. Lead poisoning. *Annu. Rev. Med.* 55, 209-222, 2004.
- 9 Odell, L. Reducing Lead in School Drinking Water: A Case Study. *School Business*  
10 *Affairs* (Dec. 1991): 14-18. 1991.
- 11 O'Flaherty, E. J. A physiologically based kinetic model for lead in children and adults.  
12 *Environ. Health Perspect.* 106(Suppl 6): 1495-1503, 1998.
- 13 Osawa, T. Treatment of Lead in Water Pipe in Osaka City. *Osaka and its Technology*  
14 *Magazine* 42, 28-37, 2002
- 15 Patch, S. Personal communication with Marc Edwards on 11/28, 2006.
- 16 Parks, J., and Edwards, M. 2008. Report to the City of Raleigh (NC) Lions Recreation  
17 Center.
- 18 Potula, V., Serrano, J., Sparrow, D., Hu, H. Relationship of Lead in Drinking Water to  
19 Bone Lead Levels Twenty Years Later in Boston Men: The Normative Aging Study,  
20 *Journal of Occupational & Environmental Medicine* 41(5), 349-355, 1999.
- 21 Powell M., 1999. *Science at EPA: Information in the Regulatory Process*. Resources for  
22 the Future, Washington, DC.
- 23 Raab, G.M., Laxen, D.P.H., Fulton, M. Lead from dust and water as exposure sources for  
24 children, *Environ. Geochem. Health* 9(3-4):80-85, 1987.
- 25 Rabinowitz, M., Leviton, A., Needleman, H., Bellinger, D., Waternaux, C.  
26 Environmental correlates of infant blood lead levels in Boston, *Environ. Res.* 38, 96-  
27 107, 1985.
- 28 Rabinowitz, M., Personal communication on 12/10/2006.
- 29 Ramsay, C. Scottish new homes lead survey. Stage 2. Scottish centre for infection and  
30 environmental Health. 2003. Accessed on 1/15/2010 at  
31 [http://www.documents.hps.scot.nhs.uk/environmental/scottish-new-homes-lead-](http://www.documents.hps.scot.nhs.uk/environmental/scottish-new-homes-lead-survey/scottish-new-homes-stage-2.pdf)  
32 [survey/scottish-new-homes-stage-2.pdf](http://www.documents.hps.scot.nhs.uk/environmental/scottish-new-homes-stage-2.pdf)
- 33 Renner, R. Public Health: Plumb Crazy. *Science*, 315(5819), p. 1669, 2007.
- 34 Renner, R. Exposure on Tap: Drinking Water as an Overlooked Source of Lead. *Environ.*  
35 *Health Perspect.* 118:a68-a72, 2010 (doi:10.1289/ehp.118-a68), 2010.
- 36 Renner, R. Out of Plumb: When Water Treatment Causes Lead Contamination. *Environ.*  
37 *Health Perspect.* 117(12), A543-A547, 2009.
- 38 Robertson, E. Pitt County Health Department. Personal Communication March 24,  
39 2006.
- 40 Rust S.W., Kumar P., Burgoon D.A., Niemuth N.A., Schultz B.D. 1999. Influence of  
41 bone-lead stores on the observed effectiveness of lead hazard intervention. *Environ*  
42 *Res* 81(3): 175-184.
- 43 Ryu, J. E., Ziegler, E. E., Nelson, S. E., and Fomon, S. J. Dietary intake of lead and blood  
44 lead concentration in early infancy, *Am. J. Dis. Child* 137, 886-891, 1983.
- 45 Sandvig, A., Kwan, P., Kirmeyer, G., Maynard, B., Mast, D., Rhodes, R. T., Trussell, S.,  
46 Cantor A., Prescott, A. Contribution of Service Line and Plumbing Fixtures to Lead  
47 and Copper Rule Compliance Issues, AwwaRF 91229, Denver CO, 2008.

- 1 Sathyanarayana, S., Beaudet, N., Omri, K., Karr, C., Predicting Children's Blood Lead  
2 Levels from Exposure to School Drinking Water in Seattle, Washington, USA,  
3 *Ambulatory Pediatrics* 6(5), 288-292, 2006.
- 4 Schock, M.R. Causes of temporal variability of lead in domestic plumbing systems,  
5 *Environ Monit Assess.* 15(1):59-82, 1990.
- 6 Schock, M.R., Hyland, R. N. and Welch, M. M. Occurrence of Contaminant  
7 Accumulation in Lead Pipe Scales from Domestic Drinking-Water Distribution  
8 Systems. *Environ. Sci. Technol.*, 2008, 42 (12), pp 4285-4291.
- 9 Schwartz, B. S., Lee, B-K, Lee, G-S, Stewart, W. F., Simon D., Kelsey K., and Todd A.  
10 C. Associations of Blood Lead, Dimercaptosuccinic Acid-Chelatable Lead, and Tibia  
11 Lead with Polymorphisms in the Vitamin D Receptor and  $\delta$ -Aminolevulinic Acid  
12 Dehydratase Genes, *Environ. Health Perspect.* 108(10), 949-954, 2000.
- 13 Scott, R., Public Health Agency Response to Lead-Contaminated Drinking Water.  
14 Presented at American Public Health Association Annual Conference and Exposition,  
15 Philadelphia, PA, 2009.
- 16 Shannon, M., Graef, J. Hazard of Lead in Infant Formula (letter), *New England Journal*  
17 *of Medicine*, pp. 137-138, 1992.
- 18 Shannon, M., Graef, J.W. Lead intoxication from lead-contaminated water used to  
19 reconstitute infant formula, *Clin Pediatr* 28, 380-382, 1989.
- 20 Shannon, M.W., Etiology of Childhood Lead Poisoning. In Lead poisoning in childhood,  
21 1996, P. Brookes Pub. Co. (Baltimore). Edited by Siegfried M. Pueschel, James G.  
22 Linakis, Angela C. Anderson, 1996.
- 23 Sherlock, J.C., Ashby, D., Delves, H.T., Forbes, G.I., Moore, M.R., Patterson, W.J.,  
24 Pocock, S.J., Quinn, M.J., Richards, W.N., Wilson, T.S. Reduction in exposure to  
25 lead from drinking water and its effect on blood lead concentrations, *Human Toxicol.*  
26 3, 383-392, 1984.
- 27 Sherlock, J.C., Quinn, M.J. Relationship between blood lead concentrations and dietary  
28 lead intake in infants: the Glasgow Duplicate Diet Study 1979-1980, *Food Addit*  
29 *Contam.* 3(2), 167-176, 1986.
- 30 Showman R. Experiences with lead-free brass in the manufacture of Cast Valves and  
31 Fittings. *Proceedings American Water Works Association Annual Conference*, New  
32 York, June, 1994.
- 33 Singhal, R.A. and Thomas, J.A. ( Editors). Lead Toxicity., Urban & Schwarzenberg,  
34 Baltimore, 1980.
- 35 Slaats, N., M. Blocker and A. Versteegh. Sampling of metals at the tap: Analyses of  
36 Dutch data over the period 2004-2006. *Meteau Conference*, Turkey, October 25,  
37 2007.
- 38 Smart, G. A., Warrington, M., Dellar, D., Sherlock, J. C. Specific factors affecting lead  
39 uptake by food from cooking water, *J. Sci. Food Agric.* 34(6), 627-637, 1983.
- 40 Smart, G., Warrington, M., Evans, W.H. The contribution of lead in water to dietary lead  
41 intakes, *J. Sci. Food Agric.* 32(2), 129-133, 1981.
- 42 State of Massachusetts, Water Quality Assurance Section, Drinking Water Program.  
43 2006. Personal Communication on 11/2006.
- 44 Schock, M.R.; Wagner, I. & Oliphant, R.J. (1996). Corrosion and Solubility of Lead in  
45 Drinking Water in Internal Corrosion of Water Distribution Systems. p 131-230,

1 1996. AWWA Research Foundation/DVGW-Technologiezentrum, Denver, CO  
2 (Second Edition).

3 Stokes, L.; Onwuche, N. C.; Thomas, P.; Davies-Cole, J. O.; Calhoun, T.; Glymph, A. C.;  
4 Knuckles, M. E.; Lucey, D.; Cote, T.; Audain-Norwood, G.; Britt, M.; Lowe, M. L.;  
5 Malek, M. A.; Szeto, A.; Tan, R. L.; Yu, C.; Eberhart, M.; Brown, M. J.; Blanton, C.;  
6 Curtis, G. B.; Homa, D. M. "Blood lead levels in residents of homes with elevated  
7 lead in tap water—District of Columbia, 2004". *MMWR Morbidity and Mortality*  
8 *Weekly Report*, 2004, 53, 268–270.

9 Taylor, P.. Deputy Director of Facilities Management. District of Columbia Public  
10 Schools. Personal Communication, November 2, 2007

11 Triantafyllidou, S., Parks, J., Edwards, M. Lead Particles in Potable Water. *Journal*  
12 *American Water Works Association*, 99(6), 107-117, 2007.

13 Triantafyllidou, S., Nguyen, C, and Edwards, M. Contribution of Galvanic Corrosion to  
14 Lead (Pb) in Water after Partial Lead Service Line Replacements", Water Quality  
15 Technology Conference, Seattle, 2009a

16 Triantafyllidou, S., Raetz, M., and Edwards, M. Lead in Drinking Water and Associated  
17 Public Health Risk, AWWA Annual Conference, San Diego, 2009b.

18 Troesken, W. *The Great Lead Water Pipe Disaster*. Cambridge, Mass.: MIT Press, 2006

19 US Environmental Protection Agency (EPA). 2002. Users guide for the Integrated  
20 Exposure Uptake Biokinetic Model for Lead in Children (IEUBK) Windows Version-  
21 32 bit Version. Office of solid waste and emergency response, Washington DC  
22 20460.

23 US EPA, 2004. Controlling Lead in Drinking Water for Schools and Day Care Facilities:  
24 A Summary of State Programs. Accessed on 7/17/2010 at  
25 [http://www.epa.gov/safewater/lcrrm/pdfs/report\\_lcrrm\\_schoolsummary.pdf](http://www.epa.gov/safewater/lcrrm/pdfs/report_lcrrm_schoolsummary.pdf)

26 US EPA. Air quality criteria for lead, Volume 1, 2006a. EPA/600/R-5/144aF.

27 US EPA. Method 200.8: Determination of Trace Elements in Waters and Wastes by ICP-  
28 MS. Revision 5.4. Environmental Monitoring Systems laboratory, Office of Research  
29 and Development, US Environmental Protection Agency, Cincinnati, Ohio 45268.  
30 1994.

31 US EPA. Lead in your Drinking Water Factsheet. EPA 810-F-93-001, 1993.

32 US EPA. Safe Drinking Water Act Lead and Copper Rule (LCR). In Federal Register,  
33 1991; Vol. 56, pp 26460-26564

34 US EPA, 2000. Federal Register /Vol. 65, No. 8, p. 1965.

35 USEPA. 3Ts for Reducing Lead in Drinking Water in Schools. Revised Technical  
36 Guidance, EPA 816-B-05-008, 2006b. Accessed on 6/8/08 at  
37 [http://www.epa.gov/OGWDW/schools/pdfs/lead/toolkit\\_leadschools\\_guide\\_3ts\\_leadschools.pdf](http://www.epa.gov/OGWDW/schools/pdfs/lead/toolkit_leadschools_guide_3ts_leadschools.pdf)

38

39 US EPA. Lead in Drinking Water in Schools and Non-Residential Buildings. EPA 812-  
40 B-94-002. Assessed on 6/8/2008 at  
41 [www.epa.gov/safewater/consumer/leadinschools.html](http://www.epa.gov/safewater/consumer/leadinschools.html)

42 US EPA. Questions About the Disposal of Lead-Contaminated Items. Accessed on  
43 15/11/2009 at <http://www.epa.gov/osw/hazard/tsd/lead/faq.htm>

44 US EPA. Private Drinking Water Wells, 2006c. Accessed on 3/4/2010 at  
45 <http://www.epa.gov/safewater/privatewells/index2.html>

- 1 US EPA. Strict Lead Air, Dust Rules Spur EPA to Focus On Drinking Water Risks.  
2 *Inside EPA Newsletter*, 06/04/2010.
- 3 US Department of Health and Human Services, Healthy People 2010: Understanding and  
4 Improving Health. Washington, DC. 2000. Accessed at <http://www.healthypeople.gov>  
5 on 5/15/2009.
- 6 US Department of Health and Human Services. Proposed Healthy People 2020  
7 Objectives. Washington, DC. Accessed at  
8 <http://www.healthypeople.gov/hp2020/Objectives> on 2/2/2010.
- 9 US Census. 2000. Year Structure Built and Year Household Moved Into Unit [Table QT-  
10 H7]. Washington, DC: US Census Bureau. Accessed on 6/29/2010 at  
11 [http://factfinder.census.gov/servlet/QTTable?\\_bm=y&-geo\\_id=01000US&-  
qr\\_name=DEC\\_2000\\_SF3\\_U\\_QTH7&-ds\\_name=DEC\\_2000\\_SF3\\_U](http://factfinder.census.gov/servlet/QTTable?_bm=y&-geo_id=01000US&-<br/>12 qr_name=DEC_2000_SF3_U_QTH7&-ds_name=DEC_2000_SF3_U)
- 13 US Congressional report by the Majority Staff of the Subcommittee on Investigations  
14 and Oversight of the Committee on Science and Technology, U.S. House of  
15 Representatives to Subcommittee Chairman Brad Miller. *A Public Health Tragedy:  
16 How Flawed CDC Data and Faulty Assumptions Endangered Children's Health*, 5/20,  
17 2010. Accessed on 10/20/2010 at  
18 [http://democrats.science.house.gov/Media/file/Commdocs/hearings/2010/Oversight/20  
may/Staff%20Report\\_DC%20Lead\\_5.20.10.pdf](http://democrats.science.house.gov/Media/file/Commdocs/hearings/2010/Oversight/20<br/>19 may/Staff%20Report_DC%20Lead_5.20.10.pdf)
- 20 Watt, G.C.M., Gilmour, W.H., Moore, M.R., et al. Is lead in tap water still a public health  
21 problem? An observational study in Glasgow. *British Medical Journal* 313, 979-981,  
22 1996.
- 23 Weston, R. F., Inc. [Weston] and Economic and Engineering Services, Inc. (EES). Lead  
24 service line replacement, a benefit-to-cost ratio analysis, American Water Works  
25 Association and Water Industry Technical Action Fund, Denver, 1990
- 26 Wetmur, J. G., Lehnert, G., Desnick, R. J. The delta-aminolevulinate dehydratase  
27 polymorphism: higher blood lead levels in lead workers and environmentally exposed  
28 children with the 1-2 and 2-2 isozymes, *Environ Res.* 56, 109-119, 1991.
- 29 WHO, 1993. Guidelines for drinking-water quality, second edition. Accessed on  
30 5/12/2009 at [http://www.who.int/water\\_sanitation\\_health/dwq/2edvol1c.pdf](http://www.who.int/water_sanitation_health/dwq/2edvol1c.pdf)
- 31 WHO, Safety evaluation of certain food additives and contaminants. WHO Food  
32 Additives Series, No. 44, 2000.
- 33 Williams, J. PTA President of a Baltimore City school. Personal Communication, 23  
34 July, 2008.
- 35 Worth, D., Matranga, A., Lieberman, M., De Vos, E., Karelekas, P., Ryan, C., Craun, G.  
36 Lead in drinking water: the contribution of household tap water to blood lead levels.  
37 In: Lynam DR, Piantanida LG, Cole JF (eds): Environmental Lead. New York:  
38 Academic Press, 199-225, 1981.
- 39 Zietz, B., Dassel de Vergara, J., Kevekordes, S., and Dunkelberg, H. Lead contamination  
40 in tap water of households with children in Lower Saxony, Germany, *Sci. Total  
41 Environ.* 275, 19-26, 2001.

FIGURES AND TABLES (in the order they are discussed in the text)

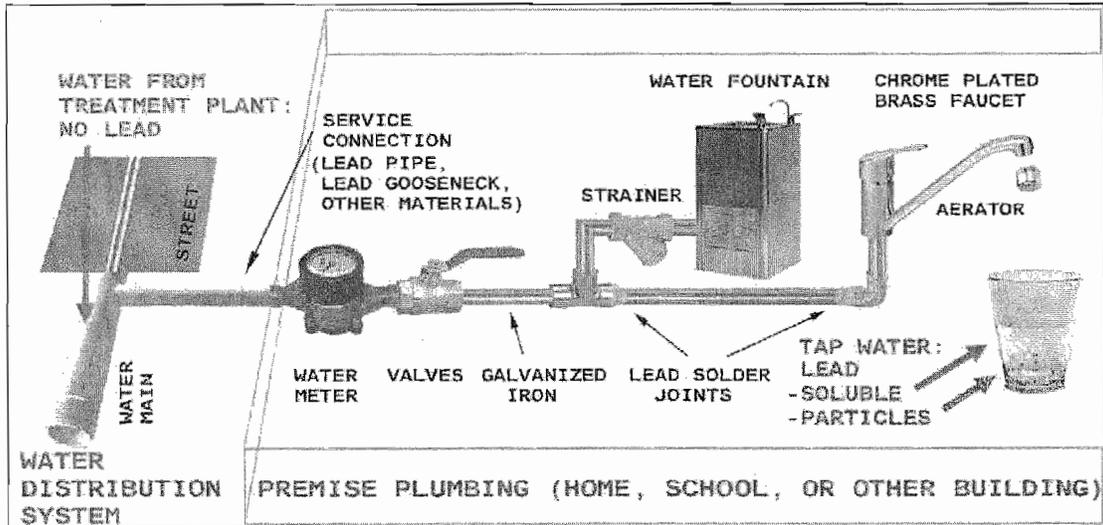
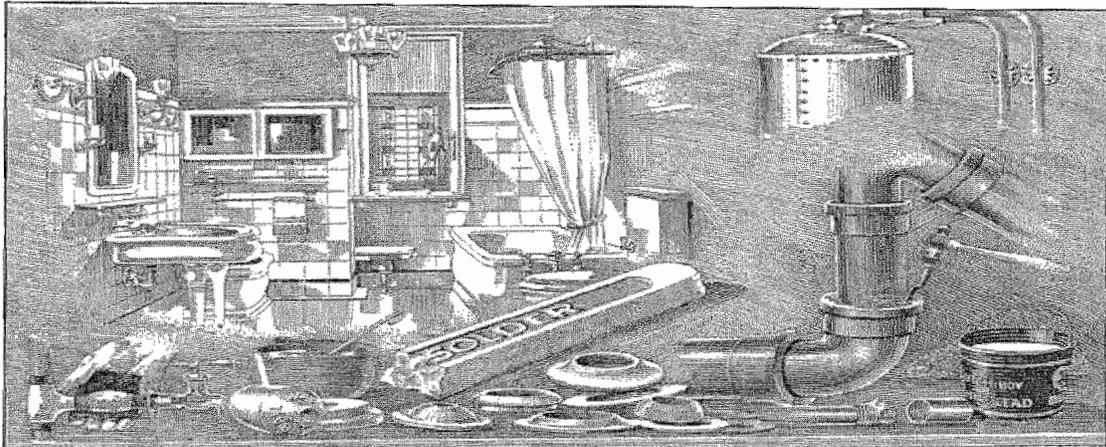


FIGURE 1: Potential sources of lead contamination in tap water of homes, schools and other buildings.



## Lead helps to guard your health

**FIGURE 2:** Advertisement of the National Lead Company promoted the use of lead in various products, including piping. The accompanying text stated that lead in water heaters, paint and piping was invaluable in assuring comfort and proper sanitation (National Geographic, 1923).

**TABLE 1:** Estimated number of US homes at potential risk from tap water lead contamination, depending on presence of lead-bearing plumbing materials. The year 1986 marked the federal ban of lead pipe and lead solder, and established a maximum lead content of 8% by weight for “lead-free” brass plumbing components.

Lead-Bearing Plumbing Material	Age of US Homes at Potential Risk	Estimated number of US homes at potential risk	Estimated Mass of Lead per home at potential risk (kg)
Brass Plumbing Components			
If 2% lead by weight	All	All	0.1 <sup>b</sup>
If 8% lead by weight	All	All	0.3 <sup>b</sup>
> 8% lead by weight	Pre 1986	81million <sup>a</sup>	0.4 <sup>b</sup>
Lead pipes, lead service lines, and lead goosenecks (100% lead by weight)	Pre 1986	3.3 million-6.4 million <sup>c</sup>	19.1 <sup>d</sup>
Lead solder (40% - 50% lead by weight)	Pre 1986	81 million <sup>a</sup>	Highly variable, but believed very significant <sup>e</sup>
Lead joints in water mains (100% lead by weight)	Pre 1986	All homes served by water mains installed pre 1986	Unknown but believed inconsequential <sup>f</sup>

<sup>a</sup>Estimation based on year of home built from US Census (2000)

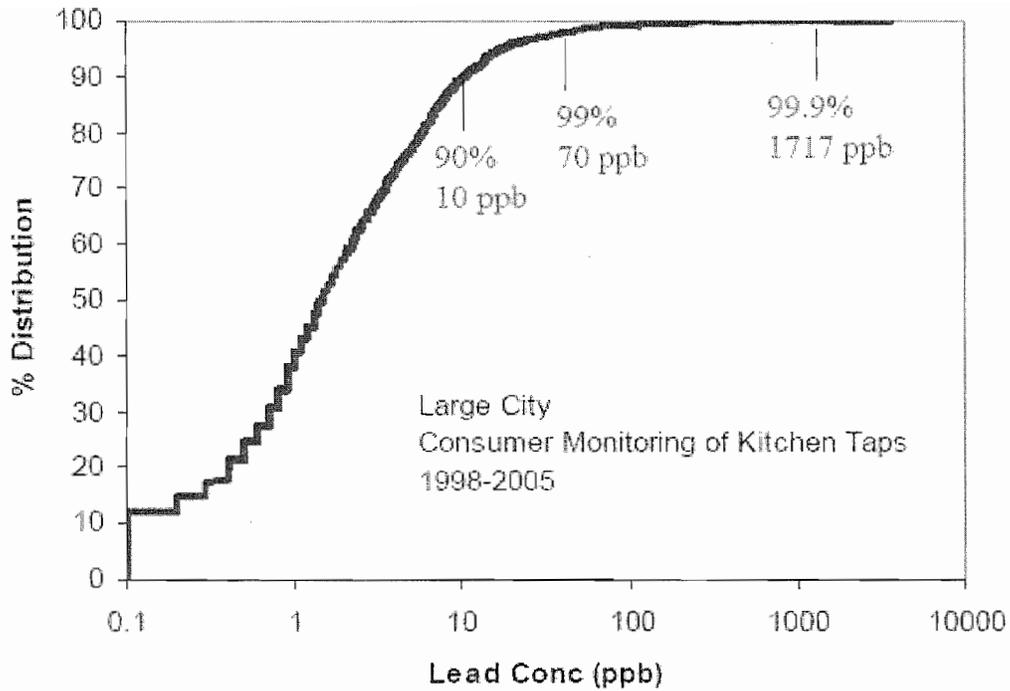
<sup>b</sup>Assumed one residential brass water meter of body weight 5 lbs (2.3 kg) and eight brass devices similar to brass ball valves of individual body weight 0.5 lbs (0.2 kg)

<sup>c</sup>Estimation by Weston and EES (1990). More recent estimations have not been conducted

<sup>d</sup>Calculation for typical lead service line of 25 ft (7.6 m) length, internal diameter of ¾ inch, external diameter of 1 inch, and lead density of 11.3 g/cm<sup>3</sup>

<sup>e</sup>Depends on workmanship of the soldering process at joints and resulting mass of solder in contact with water, believed one of the major sources of tap water lead contamination

<sup>f</sup>Currently believed that lead in these lead joints will not contact the water



**FIGURE 3:** Cumulative distribution of lead-in-water levels (in logarithmic scale) at consumers' home taps in a large US city from 1998 to 2005. Compiled from monitoring data of city residents, who voluntarily collected tap water samples and submitted them for lab analysis (Patch, 2006).

**TABLE 2:** US federal regulations and guidelines for lead in drinking water of homes and schools.

<b>Federal Statute</b>	<b>Lead and Copper Rule (LCR) of 1991 for homes served by public water systems</b>	<b>Lead Contamination Control Act (LCCA) of 1988</b>	<b>No regulation</b>
<b>Applies to</b>	- Homes and other buildings served by a public water system (~85% of US homes) - Schools/daycares regulated as “public water systems” * (~10% of US schools)	Schools/daycares served by a public water system (~90% of US schools)	Homes with private water system (~15% of US homes)
<b>Enforceable?</b>	Yes, federal regulation	No, voluntary guidance	Not Applicable
<b>Required sample number</b>	5-100 taps, depending on the size of the population served (reduced to 5-50 taps, for utilities previously compliant with the rule)	Each school water outlet used for drinking and cooking	None
<b>Sampling Frequency</b>	every 6 months (reduced to as little as once every 3 years for utilities previously compliant with the rule)	Not specified	None
<b>Sampling Requirements</b>	1 Liter cold water samples after at least 6 hours of stagnation	250 mL cold water samples after 8-18 hours of stagnation	None
<b>Lead Limit</b>	15 µg/L, termed “Action level” (AL)	20 µg/L	None
<b>“Failure criterion”</b>	Over 10% of samples exceeding AL of 15 µg/L lead (or else 90 <sup>th</sup> percentile lead > AL)	Any water sample exceeding 20 µg/L lead	None
<b>Remediation Measures</b>	Corrosion control optimization, lead service line replacement, public education	Flushing, point-of-use filters, remove plumbing, bottled water, public education	None
<b>Reference</b>	US EPA, 1991	US EPA, 2006b	US EPA, 2006c

\*Schools that regularly provide water to at least 25 individuals per day and use their own water source (e.g., private well), or treat, or sell their water, are regulated as “public water systems”.

**TABLE 3: Representative Case Studies on Lead-in-Water Problems at US Schools.**

School System Location	Year School Knew of Problem	Year Public Informed	How Discovered	Average % taps above LCCA Guidance of 20 µg/L*	Highest Reported Pb in water (µg/L)	References
Baltimore, MD	1992	2003	Parent inquired as to why water fountains had been turned off and a teacher turned whistleblower.	20% of fountains	655	City of Baltimore, 2007 Williams, 2008
Seattle, WA	1990	2003	A parent was concerned due to discolored water, collected and analyzed sample finding high lead.	1990: 33-40% 2004: 25%	1,600	Odell, 1991 Cooper, 2008 Boyd et al., 2008a
Philadelphia, PA	1993	1998	A source "unofficially" provided lead-in-water test results to EPA, after EPA had been told to get a search warrant when requested to sample water.	2000: 38% of fountains 48% of faucets	N/A but 17% of schools > 100 µg/L	Fitzgerald, 2000 Bryant, 2004
Washington, DC	1987	2007	Freedom of Information Act (FOIA) requests by Virginia Tech. More than 80% of taps in some schools exceeded 15 µg/L lead*	2004: 4% 2006: 29% 2007: 13% 2008: 26%	2004: <b>7,300</b> 2006: 4,936 2007: <b>20,000</b> 2008: 1,987	Taylor, 2007 Lambrinidou & Edwards, 2008 Lambrinidou et al., 2010
Washington Suburban, MA	2004	2004	School system voluntarily collected samples to participate in LCCA after problems were revealed in Washington DC	2004: 18%	<b>36,372</b>	Gerwin, 2004 Montgomery County Public Schools, 2004
Los Angeles, CA	1998	2008	Local news station. School personnel falsified daily reports regarding remedial flushing to reduce lead.	2008: 30%	N/A	Lambrinidou et al., 2010 Grover, 2008a; 2008b

N/A: Not Available

\*All data from Washington DC schools in this table use 15 µg/L as a failure criterion

**Bold italics indicate lead-in-water levels that were high enough (i.e., > 5000 µg/L) to classify the drinking water as "hazardous waste", based on the Toxicity Characteristic Leaching Procedure (TCLP) test, which regulates lead in waste at a level of 5 ppm or else 5,000 µg/L (US EPA, 2009)**

183

**TABLE 4:** Public health guidance regarding various levels of lead in tap water.

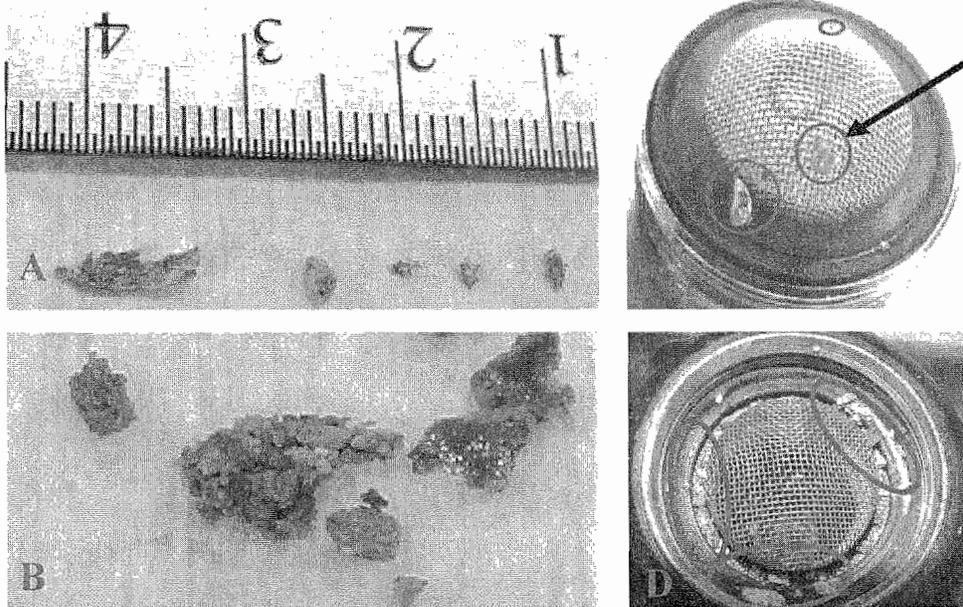
Agency	Lead Threshold (µg/L)	Health Guidance and/or Warning	Reference
US Environmental Protection Agency	0	Maximum Contaminant Level Goal (MCLG), below which there is no known or expected risk to health	US EPA (1991)
California Environmental Protection Agency	2	Public Health Goal (PHG) for all age groups	Cal/EPA (1997)
Health Canada	10	Maximum Acceptable Concentration (MAC) based on chronic health effects, for all age groups	Health Canada (1992)
World Health organization	10	Health-based guideline for all age groups	WHO (1993)
CDC	15	Children and pregnant women should not drink the water	CDC (2010a)
US Environmental Protection Agency	40	Imminent and substantial endangerment to children (warning removed in 2004)	Renner (2010)
US Consumer Product Safety Commission	700*	Acute Health Risk to children	CPSC (2005)
US Environmental Protection Agency	5000 <sup>#</sup>	Hazardous Waste classification	US EPA (2009)

\*lead dose of 175 µg translated to lead exposure through water consumption of 250 mL (one glass)

<sup>#</sup>based on the Toxicity Characteristic Leaching Procedure (TCLP) test for waste

**TABLE 5:** Classification of lead species in tap water and distinction between dissolved lead and particulate lead. Adapted from De Rosa and Williams (1992).

Operational Definition	Approximate Diameter Size ( $\mu\text{m}$ -log scale)	Class	Example(s)
<i>"Dissolved"</i> <i>Lead</i>	0.001	Free aquo ions	$\text{Pb}^{+2}$
		Organic chelates, other inorganic ions, ion pairs and complexes	Pb-EDTA $\text{PbCO}_3$
	0.01	Bound to macromolecules	Pb-fulvic acid complexes
	0.1	Highly dispersed colloidal material	Adsorbed on hydrous iron and manganese oxide colloids
	0.45	Adsorbed on inorganic particulates	Adsorbed on hydrous iron and manganese oxides and clay minerals
<i>"Particulate"</i> <i>Lead</i>	10+	Minerals and precipitates	$\text{PbCO}_3(\text{s})$ -Cerussite $\text{Pb}_3(\text{CO}_3)_2\text{OH}_2(\text{s})$ -Hydrocerussite



**FIGURE 4:** Lead-bearing particles were identified as the cause of severe tap water contamination during field investigations. (A, B) Brass particles trapped in two different strainers adjacent to two drinking water fountains at UNC, Chapel Hill-Photos from Elfland et al., (2010). (C) Lead solder particles trapped in home faucet aerator screen in Washington, DC-Photo from Edwards (2005). (D) Lead solder particles trapped in home faucet aerator screen in Greenville, NC- Photo from Triantafyllidou et al. (2007).

**TABLE 6:** Origin of representative lead particles identified in drinking water during field investigations, and level of resulting water contamination.

Location of case study	Surface composition of Lead-Bearing Particle(s)	Origin of lead particle(s)	Total Pb Concentration in Water (federal standard is 15 µg/L)	Documented Lead Poisoning?	Reference(s)
University of North Carolina at Chapel Hill, NC	3-22 %Pb, 26-66% %Cu 4-40 %Zn (3-19 %Fe, 0% Sn)	Leaded Brass	Up to 350 µg/L	No	Elfland et al. (2010)
Greenville, NC	4 – 51% Pb 1-70% Sn (0-6% Cu)	Lead Solder	Up to 10,500 µg/L	Yes	Triantafyllidou et al. (2007)
Durham, NC	17-52% Pb 37-66% Sn	Lead Solder	Up to 650 µg/L	Yes	Edwards et al. (2006)
Raleigh, NC	3% Pb 97% Sn	Lead Solder	2,413 µg/L	No	Parks and Edwards (2008)
Manchester, ME	Pb and Sn (levels not specified)	Lead Solder	Up to 3,200 µg/L	Yes	Unpublished (2006)
Washington D.C. (after partial lead service line replacement)	Unknown, but presumably metallic lead (i.e., 100% Pb) and lead rusts	Lead Service Line	Up to 190,000 µg/L	Yes	Frumkin (2010) DC WASA (2008)
Washington, D.C.	63% Pb 37% Sn	Lead Solder	Not available	No	Edwards (2005)
Washington D.C.	Not analyzed	Lead solder, leaded brass	Up to 974 µg/L*	Yes	Unpublished (2008)
Washington DC Suburban Area	1.6-9.9 % Pb, 60-79% Sn, 1.8-5.0% Cu	Lead Solder, leaded brass	Up to 1,403 µg/L*	No	Unpublished (2006)
Small Community, TN	Not Analyzed	Lead Solder, Confirmed onsite via Spot Test	Up to 2,886 µg/L	No	Edwards et al. (2007)

\*Aside from lead and tin presence, high amounts of copper and zinc in water samples suggested that brass was also contributing to the problem.

**TABLE 7:** Blood lead level (BLL) and adverse health effects in children and in adults . The “Blood lead level of Concern” is currently set at 10 µg/dL. Adapted from Troesken (2006) and National Research Council (1993).

BLL (µg/dL)	Age Group	
	Children	Adults
	Adverse Health Effects	
<10	IQ (-), Hearing (-), Growth (-)	Uncertain
>10	Erythrocyte protoporphyrin (+)	Hypertention
>20	Nerve conduction (-)	Erythrocyte protoporphyrin (+)
>30	Vitamin D metabolism (-)	Systolic blood pressure (+) Hearing (-)
>40	Hemoglobin synthesis (-)	Nerve conduction (-), infertility (men), kidney failure
>50	Colic, frank anemia, kidney failure, brain disorders	Hemoglobin synthesis (-) frank anemia, brain disorders
>100	death	death

(-) Decreased function, (+) Increased function

Hemoglobin: the molecule which carries oxygen throughout the body

Nerve Conduction: ability to send the impulse from the nerve to the muscle.

Vitamin D: necessary for the absorption of calcium and phosphorus, and for bone growth

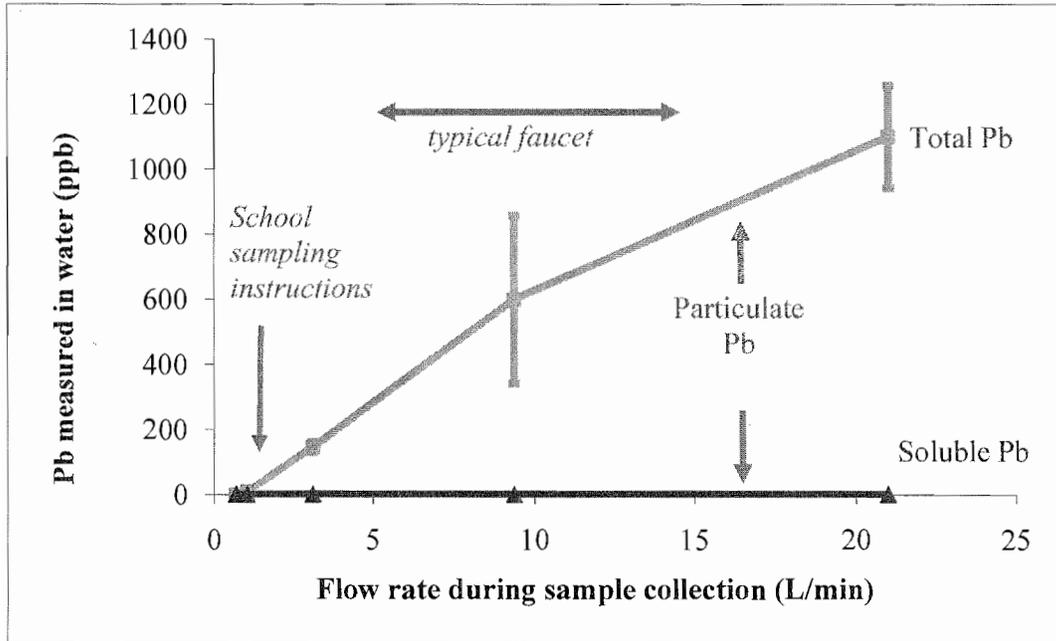
Erythrocyte protoporphyrin: Intermediate in heme biosynthesis

50  
188

**TABLE 8:** Potential difficulties in associating lead in water to lead in blood in population studies or in case studies.

Issue	Illustrative Reference(s)
<b><i>BLLs and WLLs are not always available</i></b>	
General lack of BLL measurements for sensitive populations	Binder et al., 1996
General lack of WLL measurements in schools/daycares under the LCCA	Lambrinidou et al., 2010
Relatively small number of WLL measurements under the LCR	Renner, 2009
Relative exclusion of water lead measurements during home assessments of lead-poisoned children	Renner, 2009 Scott, 2009
<b><i>WLL measurements do not always reflect actual lead in water</i></b>	
Improper water sampling/preservation methods at “high-risk” taps under the LCR: - Flow rate - Cold versus hot water - Sample preservation	Triantafyllidou et al., 2007 Triantafyllidou et al., 2009
Inherent variability in lead release from plumbing: - Spatial (fluctuations within a city, a neighborhood, or even a single home) - Temporal (fluctuations in a single tap depending on season, or even time of day)	Levin, 2008 Schock, 1990 Matthew, 1981
<b><i>Individual water consumption patterns affect individual exposure</i></b>	
Variability in individual water consumption patterns: - Amount of water consumed in/outside of home - Use of tap/filtered tap/bottled water	Troesken, 2006 Matthew, 1981
Underestimated indirect contribution of water to the total dietary lead intake: - Preparation of foods and beverages	Triantafyllidou et al., 2007 Mesch et al., 1996 Moore, 1983
<b><i>Individual risk factors affect individual response to a fixed lead dose</i></b>	
Bioavailability of lead varies between individuals, depending on: -Age -Diet -Genetics	Troesken, 2006 Lanphear et al., 2002 Matthew, 1981

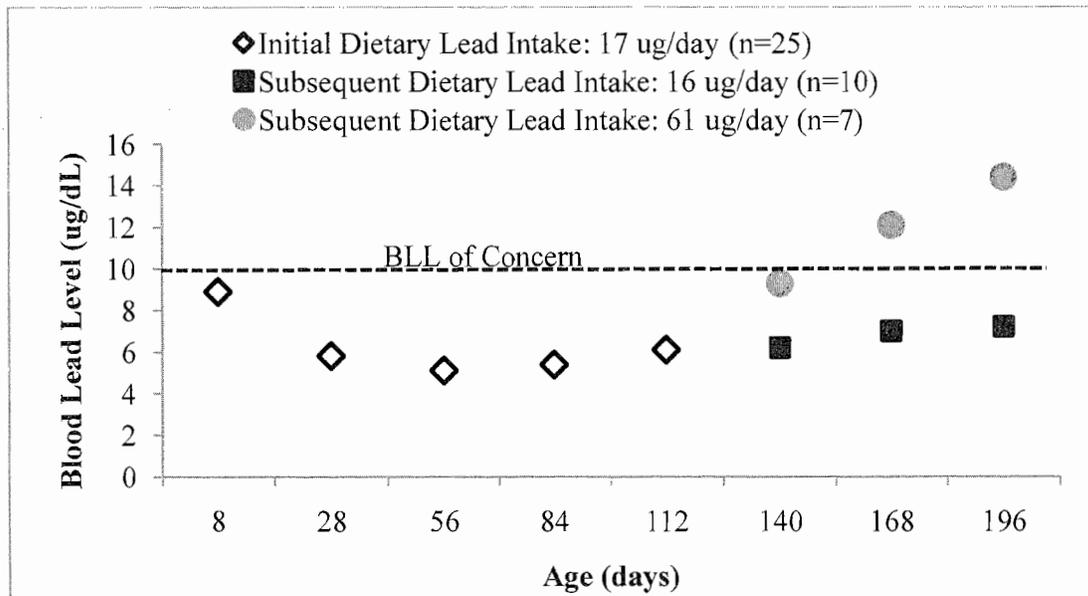
51 184



**FIGURE 5:** Lead measurement in flushed tap water samples versus flow rate in a home with lead pipe. Error bars represent 95% confidence intervals over triplicate samples collected on subsequent days at each indicated flow rate. Sample collection at the kitchen tap was timed to collect water derived from the lead pipe. (Edwards, 2005)

**TABLE 9:** Repeated flushed tap water sampling results from home of lead-poisoned child in Washington, DC. Data obtained through freedom of information act requests (Edwards, 2005).

<b>Date</b>	<b>Lead Determination (<math>\mu\text{g/L}</math>)</b>	<b>Sampling Conducted by</b>
7/26/2003	75	Water utility
3/23/2004	19	Water utility
3/23/2004	11	Department of Health
10/8/2004	21	Water utility
11/2/2004	583	Water utility



**FIGURE 6:** Average blood lead level (BLL) versus age for two groups of formula-fed infants, at two levels of dietary lead intake. Adapted from data in Ryu et al. (1983).

54  
192

**TABLE 10:** Representative population studies on the association between lead in water and lead in blood (in chronological order).

Sample Population	Independent Variable(s)	Dependent Variable	Measure of Association	Model	Reference
Different sectors of Scottish population (n=949)	First-draw water lead ( $\mu\text{g/L}$ )	Blood Lead Level ( $\mu\text{g/dL}$ )	$R = 0.52$	$\text{BLL} = 11.0 + 2.36(\text{WLL})^{1/3}$	Moore et al., 1977
Individuals in greater Boston (n=524)	First-draw water lead ( $\text{mg/L}$ ), other variables such as age, sex, education, dust lead	Blood Lead Level ( $\mu\text{g/dL}$ )	Model explains 19% of variance	$\text{Ln}(\text{BLL}) = 2.73\text{WLL} - 4.70\text{WLL}^2 + 2.17\text{WLL}^3 + \text{other terms for age, sex, education, dust [WLL was best predictor]}$	Worth et al., 1981
Mothers in Ayr, Scotland (n=114)	Kettle water lead ( $\mu\text{g/L}$ )	Blood Lead Level ( $\mu\text{g/dL}$ )	$R^2 = 0.56$	$\text{BLL} = 4.7 + 2.78(\text{WLL})^{1/3}$	Sherlock et al., 1984
Mothers in Ayr, Scotland (n=114 from 1980-81, and n=116 from 1982-83)	Kettle water lead ( $\mu\text{g/L}$ )	Blood Lead Level ( $\mu\text{g/dL}$ )	$R^2 = 0.65$	$\text{BLL} = 5.6 + 2.62(\text{WLL})^{1/3}$	Sherlock et al., 1984 Moore et al., 1985
Bottle-fed infants in Scotland (n=93)	Composite kettle water lead ( $\mu\text{g/L}$ )	Blood Lead Level ( $\mu\text{g/dL}$ )	$R = 0.57$	$\text{BLL} = 14 + 0.062\text{WLL}$  $\text{BLL} = 15.6 + 0.052\text{WLL}$ $\text{BLL} = 14.7 + 0.054\text{WLL}$ $\text{BLL} = 15.4 + 0.052\text{WLL}$	Lacey et al., 1985  WHO, 2000
Women in Wales (n=192)	Kettle water lead ( $\mu\text{g/L}$ ) Air Lead ( $\mu\text{g/m}^3$ ) Dust Lead ( $\mu\text{g/g}$ )	Blood Lead Level ( $\mu\text{g/dL}$ )	Model explains 38% of variance	$\text{Log}(\text{BLL}) = 1.06 + 0.62(\text{WLL})^{1/3} + 0.18\text{Log}(\text{ALL}) - 0.02\text{Log}(\text{DLL})$	Elwood et al., 1985
Adults in Vosgian Mountains, France (n=155 men, n=166 women)	Tap water lead after 5 seconds of flushing ( $\text{mg/L}$ )	Blood Lead Level ( $\mu\text{g/dL}$ )	Spearman's rho = 0.30 for men = 0.47 for women	Not determined	Bonnefoy, et al., 1985
Children in Edinburgh (n=397)	Tap water lead ( $\mu\text{g/L}$ ), dust lead ( $\mu\text{g/g}$ )	Blood Lead Level ( $\mu\text{g/dL}$ )	Model explains 43% of variance	$\text{Log}(\text{BLL}) = 0.5\text{Log}(5326 + 103\text{WLL} + 3.81\text{DLL})$ [WLL was best predictor]	Raab et al., 1987
Different sectors of population in Hawaii, with rain catchment systems (n=384)	Tap water lead ( $\mu\text{g/L}$ ), other water-related terms, other terms for soil and demographics	Blood Lead Level ( $\mu\text{g/dL}$ )	linear model explains 77% of variance	Linear model:  $\text{BLL} = 5.62 + 0.025\text{WLL} + 0.0008(\text{GLASSES} * \text{WLL}) - 0.017(\text{FILTER} * \text{WLL}) + \text{other terms related to water, soil, age,}$	Maes et al., 1991

Citizens of Sainte-Agathe-des Monts, Quebec, Canada (n=72)	Average water lead from 6 samples (mg/L) and estimated daily water consumption (L/day)	Blood lead level (µg/dL)	R <sup>2</sup> =0.25	sex, ethnicity etc. BLL = 10+7 x WLL x Water Consumption (units adjusted)	Savard, 1992
School children in Southern Saxonia, Germany (n = 69 for location A, n=44 for location B)	Composite tap water lead (µg/L)	Blood Lead Level (µg/dL)	Location A: R <sup>2</sup> =0.34 Location B: R <sup>2</sup> =0.41	Location A: Log(BLL)=0.74+0.14Log(WLL) Location B: Log(BLL)=0.81+0.14Log(WLL)	Englert et al., 1994
Mothers in Glasgow, Scotland (n=342)	Water lead (µg/L)	Blood Lead Level (µg/dL)	Spearman's rho=0.39	Not determined	Watt et al., 1996
Women in Hamburg, Germany (n=142 for sub-sample with detectable water lead)	Average water lead (µg/L) from 3 specimens	Blood lead level (µg/dL)	Spearman's rho=0.43	Not Determined	Fertmann et al., 2004
Children in Washington DC (n=2698 in "High Risk" n=4791 in "Moderate Risk" n=2621 in "Low Risk")	90 <sup>th</sup> Percentile Water Lead (µg/L)	% Increase in Children with EBLL Compared to US average	R <sup>2</sup> = 0.83 in "High Risk" R <sup>2</sup> = 0.71 in "Moderate Risk" R <sup>2</sup> = 0.50 in "Low Risk"	Not Determined	Edwards et al., 2009

WLL: Water Lead Level; BLL: Blood Lead Level; DLL: Dust Lead Level; ALL: Air Lead Level

199

Elsevier Editorial System(tm) for Environmental Research

Manuscript Draft

Manuscript Number: ER-11-156

Title: Hundreds of Partial Pipe Replacements Conducted in Washington D.C. Before July 2004

Article Type: Commentary

Corresponding Author: Dr. Marc A. Edwards,

Corresponding Author's Institution: Virginia Tech

First Author: Marc A. Edwards

Order of Authors: Marc A. Edwards; Marc A Edwards, PhD; Marc A Edwards, PhD

Re: Brown, M.J., et al., Association between children's blood lead levels, lead service lines, and water disinfection. Washington, DC, 1998–2006. Environ. Res. (2010).

The recent article by Brown et al. (2010) has a section which would benefit from further analysis and/or elaboration. Specifically, the authors state that:

*"Chloramine with orthophosphate was the water disinfectant used during the period of time when the WASA LSL replacement program was conducted."*

The authors then limit their analysis to blood lead data from children living in homes with partial replacements from 7/1/2004–12/31/2006, which is indeed the time period when phosphate was in the water. However, hundreds of partial pipe replacements were conducted by WASA before 7/1/2004 and when phosphate was not in the water.

If the authors analyze **all** the data from D.C. children living in homes with partial pipe replacements, including those whose blood leads were collected before 7/1/2004, how does it impact the results that are obtained? The concern is that a decision to exclude this data might mask the magnitude (and significance) of possible adverse health impacts from partial pipe replacements. Specifically, orthophosphate was added to water to inhibit lead release, and including the data from when orthophosphate was not added, might provide stronger evidence of harm.

Marc Edwards

Charles Lunsford Professor of Civil Engineering

Virginia Tech

May 17, 2010

Testimony of Marc Edwards, PhD before the  
US House of Representatives Committee on Science and Technology, 111<sup>th</sup> Congress  
*Preventing Harm—Protecting Health: Reforming CDC's Environmental Public Health Practices*

## **EXPERIENCES AND OBSERVATIONS FROM THE 2001-2004 "DC LEAD CRISIS"**

### **INTRODUCTION**

I am the Charles Lunsford Professor of Civil and Environmental Engineering at Virginia Tech, where I conduct research at the interface of basic science, public health, corrosion control and environmental engineering. I have published over 100 peer-reviewed journal articles, made hundreds of technical presentations, and have been recognized with numerous awards including a Presidential Faculty Fellowship from the White House/National Science Foundation (1996) and a MacArthur Fellowship (2008). *Time* magazine named me amongst the 4 most important "Innovators" in water from around the world (2004) and just this year Villanova University awarded me the Praxis Award in Professional Ethics.

**Partial Lead Service Line Replacements.** My worry was reinforced when, in 2008, in partnership with a coalition of public health advocates in DC, we discovered that DC WASA's 5-year and \$100 million "accelerated" lead in water "remediation" program was not nearly the success that DC WASA and US EPA R3 had claimed. Thousands of lead water pipes were dug up and replaced with copper pipe, but only the publicly owned portion of the old lead pipe was replaced. The privately owned portion was left in the ground. This program of partial lead service line replacement-worsened lead in water levels in many homes for an undetermined duration. For years the agencies repeatedly claimed in public and in written scientific reports

(again contradicting decades of prior experience and research), that partial replacements in DC were not causing lead to spike:

"... there was no immediate change, or immediate increase in lead levels in the tap water"..." there is no evidence that the lead levels increase"..."remove half the lead...you have a lot less lead in your tap water as a result."

Rick Rogers EPA R3, Interview on WAMU Radio, May 2004

In 2004, I had testified to the US Congress that partial lead service line replacements were a waste of money and that my research had shown the procedure could increase residents' risk for lead exposure. After years of denial and false statements by DC WASA and US EPA R3, I eventually proved that the two agencies had themselves collected hundreds of data points showing severe problems with DC residents' exposure to high lead in water, following DC WASA's partial lead service line replacement "remedy" at their homes.

But the public health implications of our work were to be neutralized by what was becoming a well-oiled tag team effort by Dr. Guidotti and the CDC. Dr. Guidotti provided testimony and "public education" at community meetings, asserting that even the highest levels of lead in DC's water after partial lead service line replacement (sometimes exceeding 100,000 ppb) probably did not pose a health risk. Dr. Guidotti wrote:

"It has been alleged that spiking lead levels after partial lead service line replacements present a health risk. This is probably not correct."

Testimony of Dr. Guidotti, March 10, 2008

The CDC attended two of several DC WASA public meetings on this issue, and consistently supported Dr. Guidotti with silent acquiescence, no matter how outrageous the George Washington University professor's proclamations. The CDC repeatedly refused to answer direct questions from DC residents, that could have put Dr. Guidotti's testimony into some context. At these meetings, DC WASA distributed written "public education" materials embellishing on the already ludicrous CDC MMWR conclusion. For instance, the water utility's fact sheet stated that:

"In 2004, the CDC analyzed results from a District Department of Health examination of blood lead levels among children during the period of elevated lead levels in tap water at many homes. According to the CDC report, there were no children, from a sample group of 201, identified with blood lead levels above the CDC *level of concern* (>10 micrograms/deciliter) that were not explained by other sources, primarily the conditions of the household paint."

Even ignoring the already distorted analysis of the 201 residents portrayed in the original CDC MMWR, clearly, the CDC MMWR never looked at 201 children. The CDC MMWR itself stated that only 17 of the 201 targeted "worst-case" residents were under the age of 6. Moreover, the CDC MMWR study involved no environmental risk assessments at the homes of DC children with elevated blood lead levels. Finally, although the CDC MMWR implied that virtually all detected blood lead elevations in DC were due to lead paint, it never stated this.

197

When two DC public health advocates called on the CDC to demand that DC WASA correct the misleading presentation of the CDC's own research results, the CDC failed to do so. A CDC employee who claimed to have consulted a CDC lawyer, claimed that there was nothing CDC could do to redress the inaccuracies in already distributed versions of DC WASA's fact sheet. However, the official assured the two advocates that he would request all future versions of the DC WASA fact sheet prior to dissemination in order to correct any misleading statements. Despite that assurance, the fact sheet was once again distributed on May 1, 2008 with the same misleading language in place.

As perplexing as CDC's behavior was in relation to the above incident, what was going on behind the scenes was even worse. Unbeknownst to either myself or the DC residents who were pleading with the CDC in 2008 to correct Dr. Guidotti's and DC WASA's assertions that lead-contaminated drinking water does not pose a significant public health concern, the CDC had been researching the impacts of partial lead pipe replacements on blood lead levels of DC children probably since at least 2005.<sup>39</sup> Based on accounts of individuals who attended a November 2007 meeting between EPA, CDC, DC DOH and Dr. Guidotti, and as substantiated in later e-mails in my possession, the CDC actually had data in late 2007 that indicated public health risks from DC's partial lead service line replacements. It was not until February 2009, long after the time when disclosure of their results could have been used to prevent more needless harm to DC children, and to properly guide public debate, that CDC eventually issued online an "important update" based on their research in DC:

"CDC's Healthy Homes and Lead Poisoning Prevention Branch has conducted an epidemiological study of the relationship between children's blood levels and lead water service lines. **Our preliminary results suggest that when lead service lines are partially replaced, that is the public portion of the line from the the main to the meter is replaced, children are more likely to have blood lead levels greater than or equal to 10 µg/dL, compared to children living in housing with either undisturbed lead service lines or service lines that are not made of lead**" (bold emphasis added).

The ethics of how CDC conducted its "research work" given extensive prior knowledge about lead spikes after partial pipe replacement, their duplicity in covering up what was actually occurring to children in these homes, and their failure to inform the public about their knowledge of the potential harm throughout the numerous public meetings on this subject in 2008, strikes me as highly unethical and deserving of future scrutiny. Yet it is also completely consistent with CDC's past actions, to withhold and control any information that may cast doubt on their message that lead in water is not a significant public health concern.

**DC WASA Sampling Inconsistent with Intent of LCR.** The coalition of concerned DC residents also discovered that since 2005 DC WASA, again with the full knowledge and approval of US EPA R3, had achieved compliance with the Lead and Copper Rule by monitoring DC's water via the use of a sampling protocol that required flushing taps for 10 minutes the night before sampling. In the water industry, pre-flushing is understood as a well-known method to game the US EPA lead standard, by temporarily reducing lead concentrations at the tap. After reviewing the coalition's appeal of DC WASA's protocol, Cynthia Dougherty, the Director of US EPA HQ Office of Ground Water and Drinking Water, determined in a letter to the coalition that flushing on the eve of compliance sampling was inconsistent with the intent of the Lead and Copper Rule: