Drinking Water Quality in Hospitals and Other Buildings

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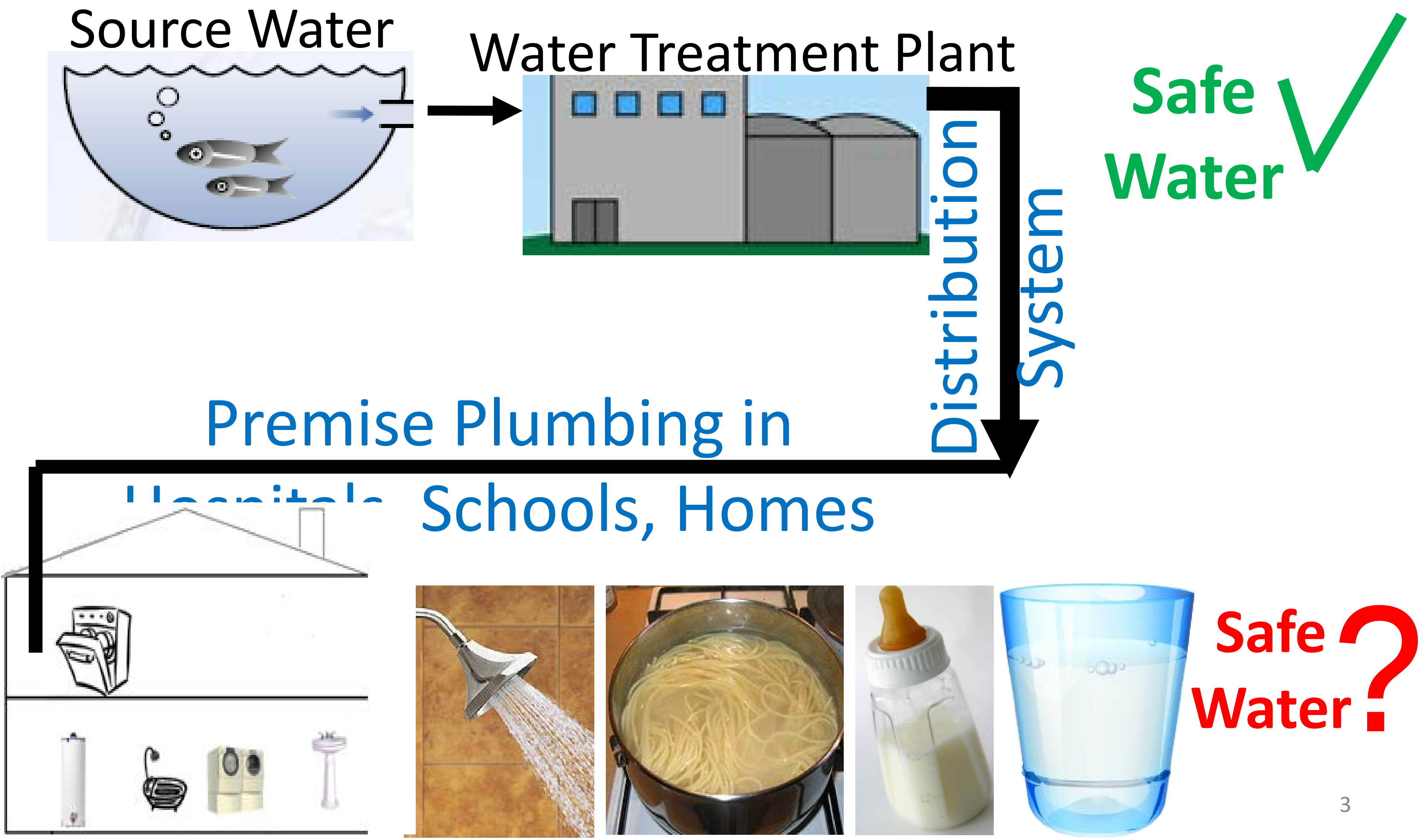
Drinking water quality at the point of use



Aging main distribution systems in the US


2013 REPORT CARD FOR AMERICA'S INFRAST
NAVIGATION MENU
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AMERICA'S INFRASTRUCTURE G.P.A.

Each category was evaluated on the basis of capacity, condition, funding, future need, operation and maintenance, public safety and resilience.

METHODOLOGY

AVIATION	D	PORTS	C
BRIDGES	C+	PUBLIC PARKS AND RECREATION	C-
DAMS	D	RAIL	C+
DRINKING WATER	D	ROADS	D
ENERGY	D	SCHOOLS	D
HAZARDOUS WASTE	D	SOLID WASTE	B-
INLAND WATERWAYS	D-	TRANSIT	D
LEVEES	D-	WASTEWATER	D

http://www.infrastructurereportcard.org/


Clogged Iron Pipe due to corrosion
http://www.wrb.ri.gov


Water Main Break
NACE, 2010

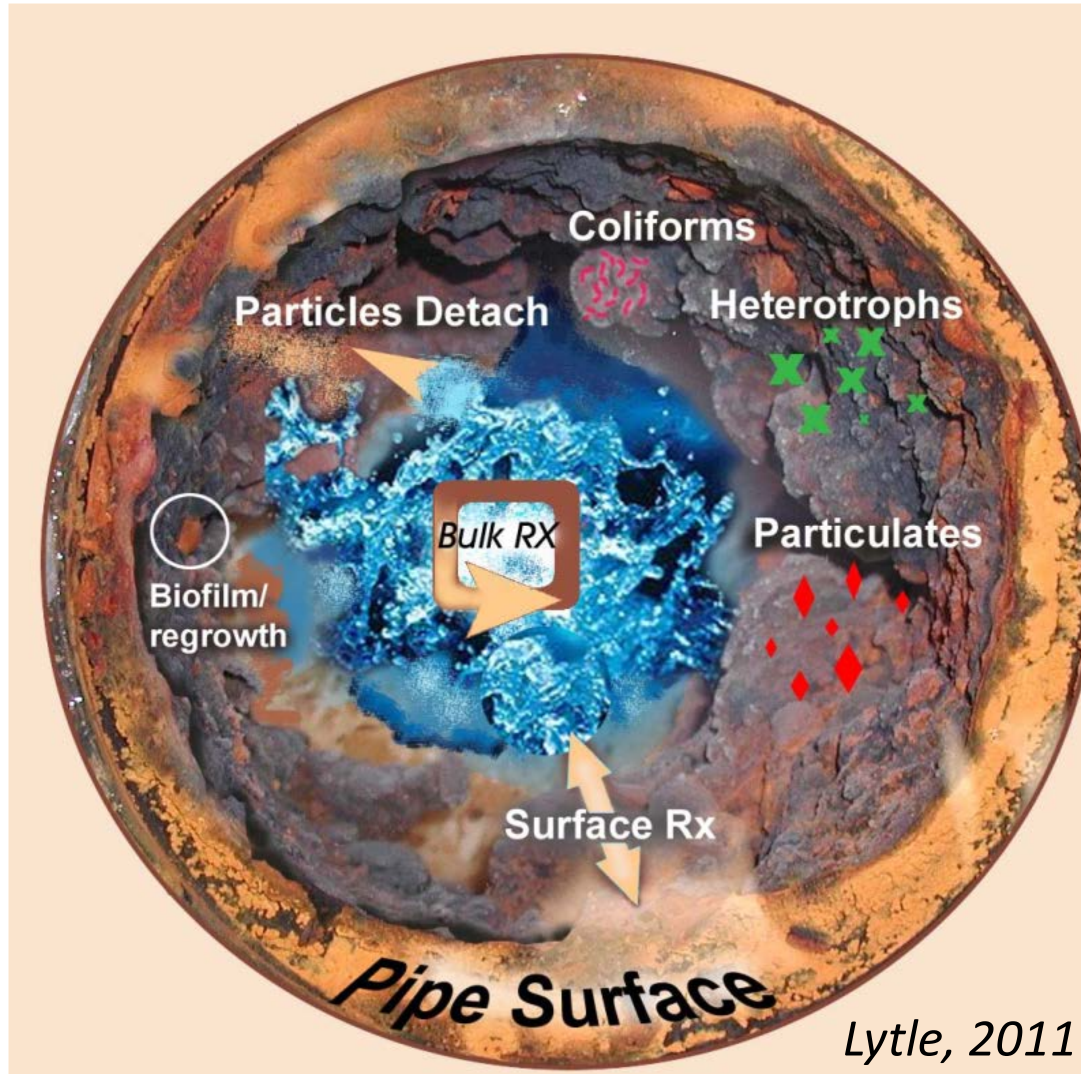
- Many DS reach or have exceeded their design lifetime
- Public health/resource/financial Implications

Aging pipes are complicated reactors that can accumulate contaminants

- Inorganic contaminants in bulk water or attached to pipe surfaces

- Microbes in bulk water or in biofilms

- Biofilms: slime layers of microorganisms adhering to surfaces

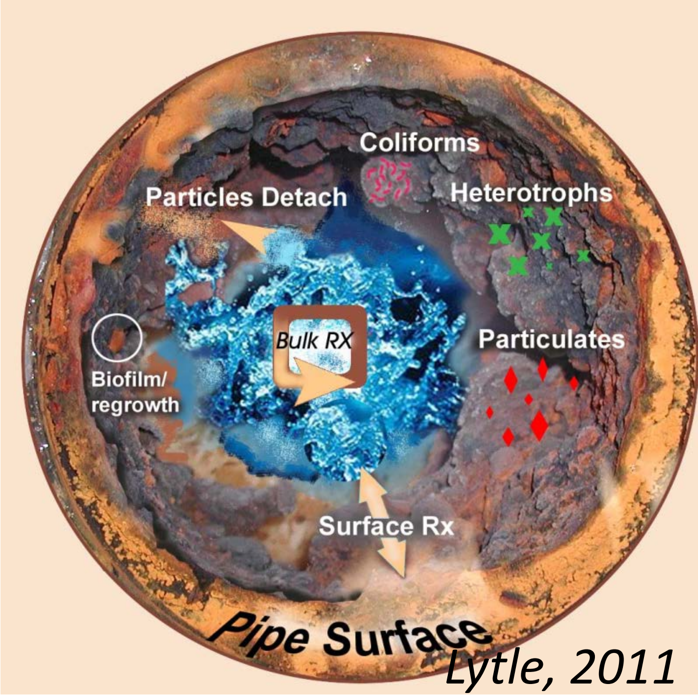


Premise plumbing challenges

<u>High Surface Area to Volume Ratio</u>

- 10X more length
- 10X surface area per unit volume
- 1/4 of the total distribution surface area
- 1/60 of the total volume

National Academy of Sciences, 2006



Lytle, 2011

Premise plumbing challenges

Every building is a dead-end

- Variety of reactive pipe materials that interact with disinfectant and bacteria

  -PVC, PEX, Galvanized, Copper, Brass, Solder, Old Lead

- Variety of plumbing configurations, installation practices (good/bad), and maintenance (good/bad)

- Water use patterns affect ***Water Age***

  - Flow: Continuous Turbulent → Long Stagnation

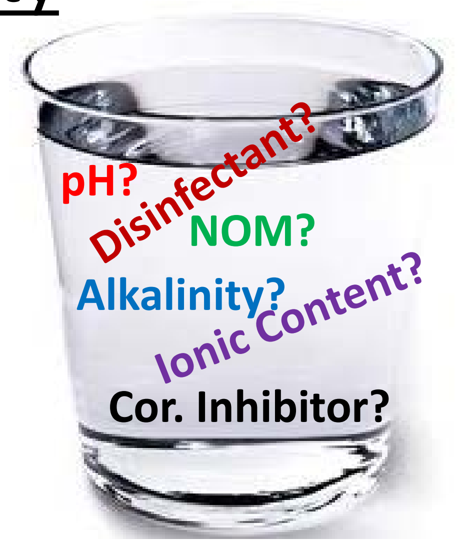
  - Temperature, Redox Potential, pH, Disinfectant Residual: Highly Variable

  - Microbes: Quantifiable diversity

Slide modified from Marc Edwards

Premise plumbing challenges

<u>Chemistry of water affects end water quality</u>



- All waters are different in terms of corrosivity and microbial re-growth potential, due to

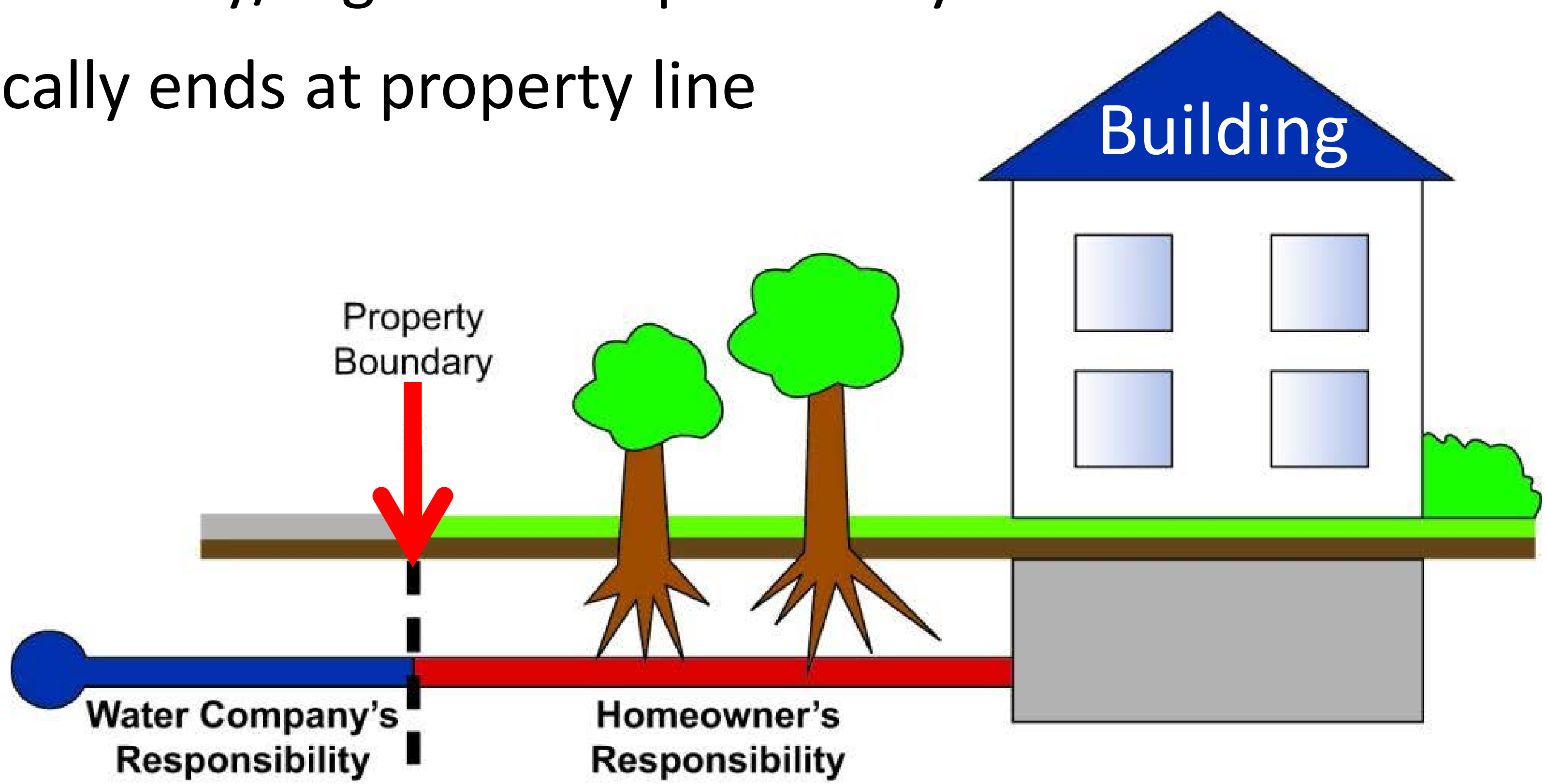
1) Source water quality
2) Water treatment steps
3) Interaction with distribution system before building

- Water that is "aggressive" for corrosion or microbial growth for certain plumbing materials/configurations might be "harmless" to next door plumbing
  - **Variability** from building to building
  - **Variability** from tap to tap (hot spots)
  - **Variability** between **hot** and **cold** water from same tap

Premise plumbing challenges

Responsible Party

Water utility/regulator responsibility typically ends at property line



http://www.homeserveusa.com

Illustrative case studies suggest that maintaining a constant acceptable end water quality is challenging

Part I: Hospitals

Part II: Schools

Part I: Hospitals

Water Research 102 (2016) 1–10

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Water Research

journal homepage: www.elsevier.com/locate/watres

Copper-silver ionization at a US hospital: Interaction of treated drinking water with plumbing materials, aesthetics and other considerations

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ABSTRACT

Tap water sampling and surface analysis of copper pipe/bathroom porcelain were performed to explore the fate of copper and silver during the first nine months of copper-silver ionization (CSI) applied to cold and hot water at a hospital in Cincinnati, Ohio. Ions dosed by CSI into the water at its point of entry to the hospital were inadvertently removed from hot water by a cation-exchange softener in one building (average removal of 72% copper and 51% silver). Copper at the tap was replenished from corrosion of the building's copper pipes but was typically unable to reach 200 μg/L in first-draw and flushed hot and cold water samples. Cold water lines had >20 μg/L silver at most of the taps that were sampled, which further increased after flushing. However, silver plating onto copper pipe surfaces (in the cold water line but particularly in the hot water line) prevented reaching 20 μg/L silver in cold and/or hot water of some taps. Aesthetically displeasing purple/grey stains in bathroom porcelain were attributed to chlorargyrite [$AgCl_{(s)}$], an insoluble precipitate that formed when CSI-dosed Ag^+ ions combined with Cl^- ions that were present in the incoming water. Overall, CSI aims to control *Legionella* bacteria in drinking water, but plumbing material interactions, aesthetics and other implications also deserve consideration to holistically evaluate in-building drinking water disinfection.

1. Introduction

Hospitals in the United States (US) and world-wide are increasingly relying on in-building disinfection to control waterborne pathogens (e.g., *Legionella pneumophila*, *Mycobacterium avium* and *Pseudomonas aeruginosa*) and ultimately prevent or mitigate disease outbreaks in sensitive patients (Falkinham et al., 2015; Pruden et al., 2013). Systemic drinking water disinfection options for buildings include free chlorine, chlorine dioxide, monochloramine, UV radiation, ozone and copper silver ionization, with each option having different presumed or proven limitations and benefits (Rhoads et al., 2015; Pruden et al., 2013; Lin et al., 2011, 1998).

The implications of in-building water treatment are not fully understood (Rhoads et al., 2015, 2014). Information is gradually being collected as more disinfection technologies become commercially available, as buildings increasingly install such systems, and as researchers, policy-makers, building managers, manufacturers and water consumers assess the full impact of such installations on water quality. During a 2013 US Environmental Protection Agency (EPA) workshop, US state representatives requested more research on the effectiveness of each disinfection treatment against *Legionella* and on water quality evaluation after in-building disinfection is applied (Triantafyllidou et al., 2014).

Given that the primary objective of water disinfection in buildings is pathogen control, it is not surprising that its impact on general water chemistry and other potential consequences are often overlooked. But as with any type of water treatment, interactions of added disinfectants with the incoming water chemistry and with building plumbing materials can have other important effects (e.g., formation of disinfection byproducts and/or metallic corrosion) which could compromise the integrity of the

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Hospitals deserve increased attention

- A recent outbreak of hospital-acquired pneumonia in Pittsburg, from waterborne *Legionella* bacteria, caused
  - Several fatalities and lawsuits
  - Congressional investigation
  - Extensive press coverage and criticism
  - Closer look at microorganisms in hospital water

TV: CNN | CNNI | CNN en Español | HLN

CNN Health

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VA under scrutiny after Legionnaires' cases in Pittsburgh

By **Nelli Black** and **Drew Griffin**, CNN
updated 6:23 PM EST, Fri December 14, 2012

Pittsburgh, Pennsylvania (CNN) -- Twenty-nine patients at the Veterans Administration hospital in Pittsburgh have been diagnosed with Legionnaires' disease since January 2011, raising questions about the institution's safety practices.

Five of the cases "are known to have acquired the disease from the hospital," the VA said. Another eight were infected elsewhere, and the source of the infection in 16 cases cannot been determined.

The spate of illnesses has led relatives of two veterans who died after contracting the disease, a type of pneumonia, to blame the hospital.

http://www.cnn.com/2012/12/13/health/legionnaires-hospital-water/

Hospitals deserve increased attention

CBS EVENING NEWS w/ SCOTT PELLEY FULL EPISO

By JENNIFER JANISCH / CBS NEWS / *March 13, 2014, 6:21 PM*

VA hospital knew human error caused Legionnaires' outbreak

Internal documents obtained last January by CBS News also indicated the Pittsburgh VA was failing to properly monitor and maintain its water system's Legionella prevention equipment, and that officials were told by a water treatment company that the hospital had legionella bacteria because "systems not being properly maintained."

http://www.cbsnews.com/news/va-hospital-knew-human-error-caused-legionnaires-outbreak/

Ice machines were source of Legionnaires‘, May 2, 2014
http://www.post-gazette.com/news/health/2014/05/02/UPMC-Pittsburgh-hospital-ice-machines-Legionella-patients/stories/201405020165#ixzz312LpSUQx

Legionnaires' Disease Outbreak Linked to Hospital's Decorative Fountain, January 9, 2012
http://www.shea-online.org/View/ArticleId/124/Legionnaires-Disease-Outbreak-Linked-to-Hospital-s-Decorative-Fountain.aspx

Microorganisms in hospitals

- Other patients
- Hospital staff
- Contaminated surfaces

- Water supply
  - Ice machines (ingestion)
  - Faucets (ingestion)
  - Showerheads (inhalation)
- Bulk water, or
- Biofilms in plumbing materials

- Even decorative fountains (inhalation)

Legionella is one opportunistic pathogen

Legionella pneumophila

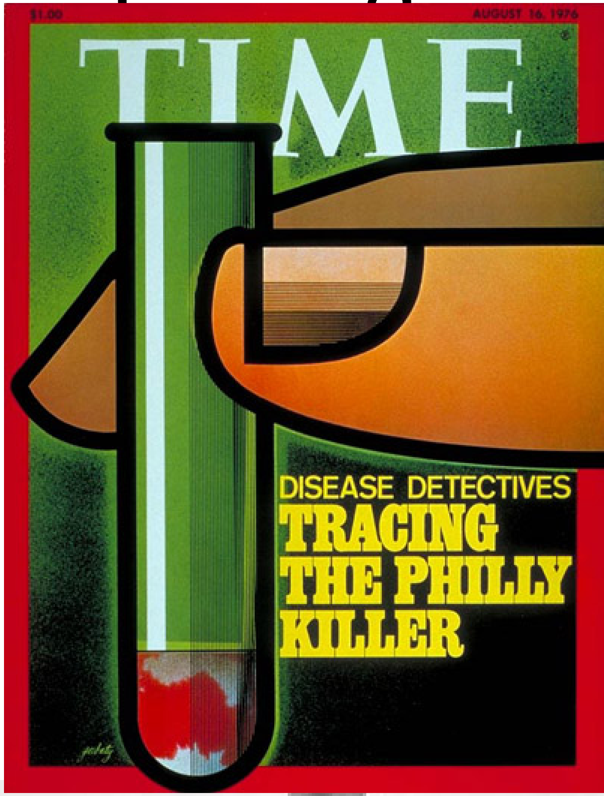
→Pontiac fever

→Pneumonia, even death to susceptible individuals with risk factors

→Primary cause of waterborne disease in the USA

→ No enforceable regulations MCLG=0, TT, listed on CCL3

→ No consensus on endpoints for remediation (how to quantify risk)



http://en.wikipedia.org/wiki/Legionella_pneumophila

Case Study 1: Large Hospital

- Buildings A and B
- Eight floors per building
- Sample water from selected nurse break rooms:

  - once every few months

  - 250 mL of **first-draw water** and 1 L of **flushed water** (3 min)

  - hot water and cold water

  - general water chemistry
- sample showerheads from patient rooms:

  - microbiological parameters in biofilms

Case Study 1: Collection of Tap Water

General Water Parameters

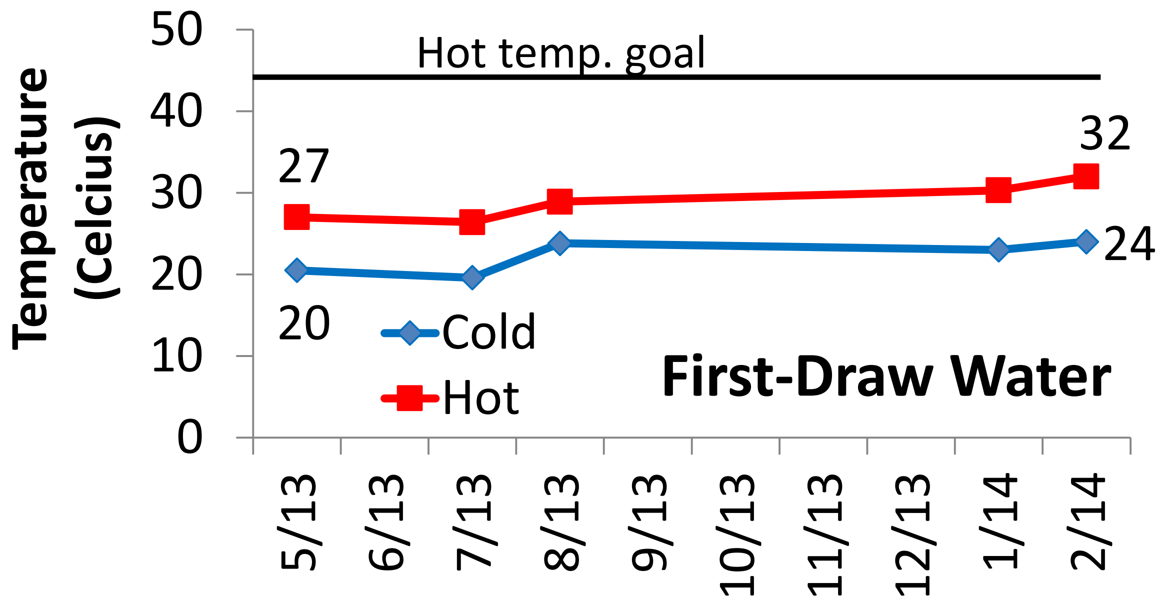
- pH
- Temp.
- Chlorine

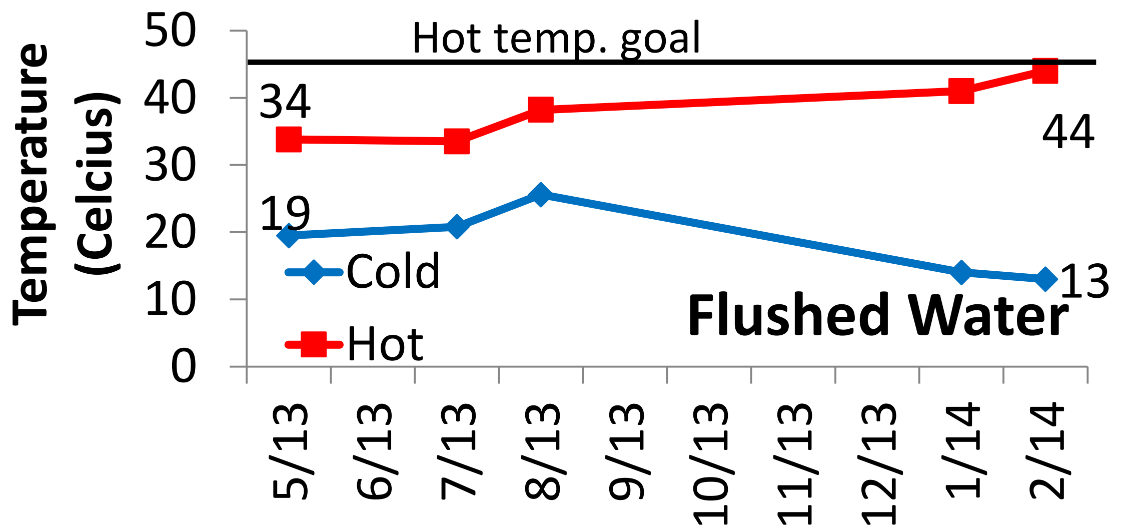
Case Study 1: Collection of Showerheads

Microbiological Parameters:

- *Legionella* bacteria in biofilms
- Other pathogens (not discussed herein)

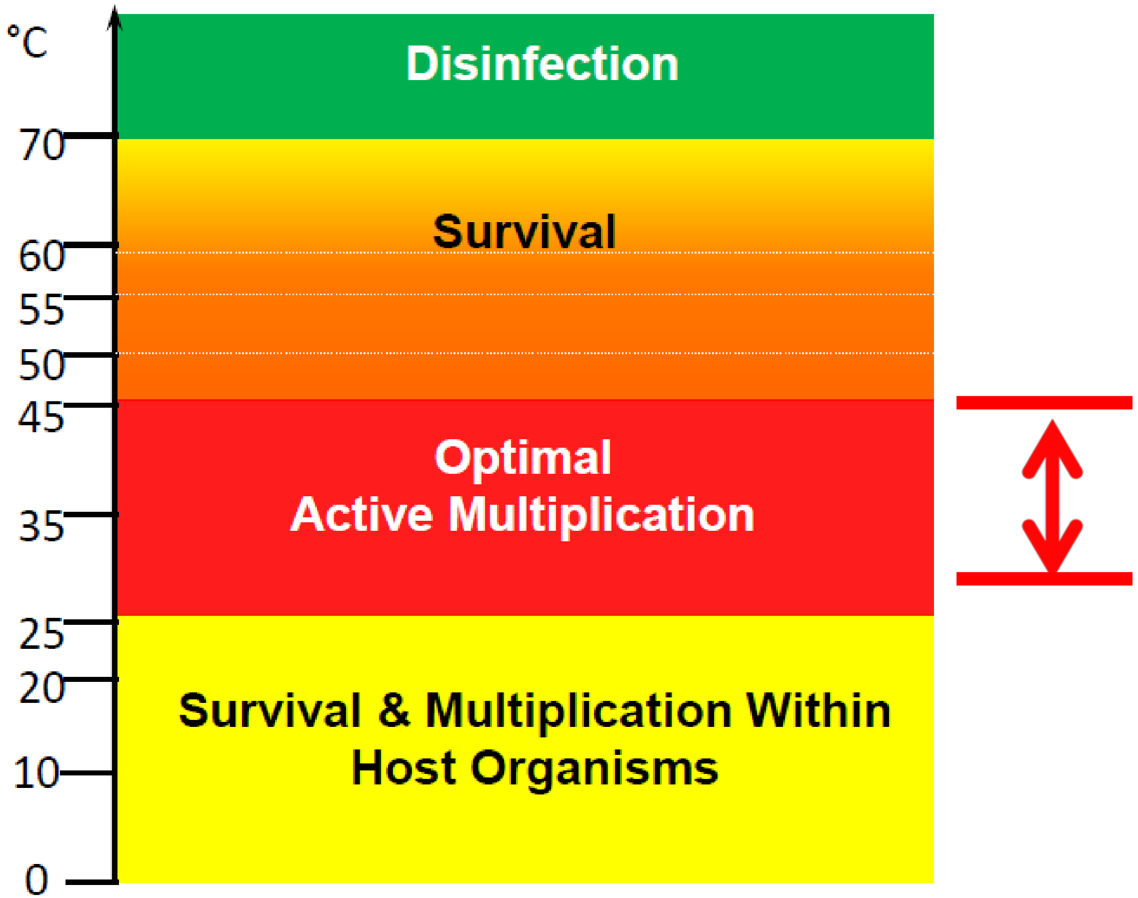
Case Study 1: Temperature variability





- Maintaining high enough hot water temperature to inactivate/kill pathogens is a first line of defense
- Not achieved in hot, first-draw water
- Flushed hot water warmer than first-draw hot water
- Tempering valves

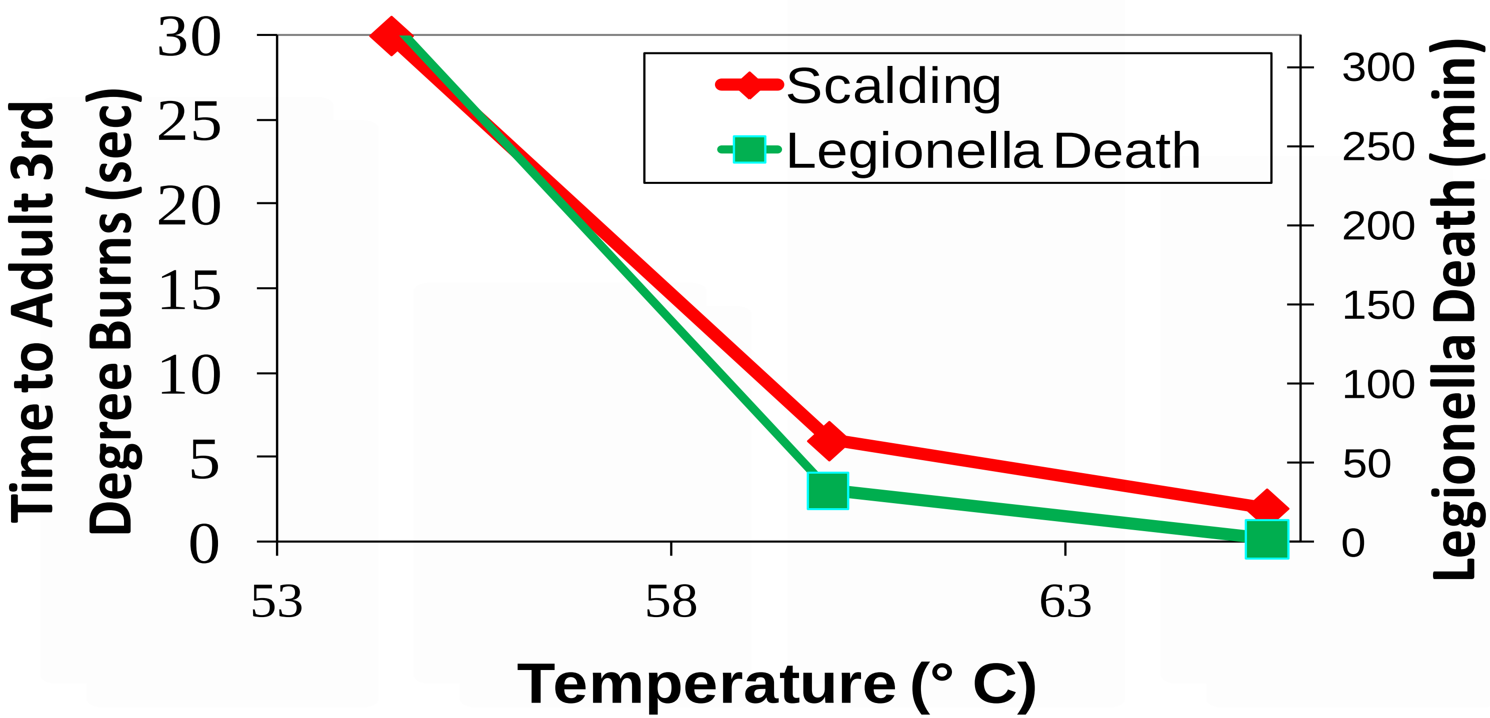
Temperature is important in controlling *Legionella*



Bedard et al., 2013

hot water temp. in range that *Legionella* like

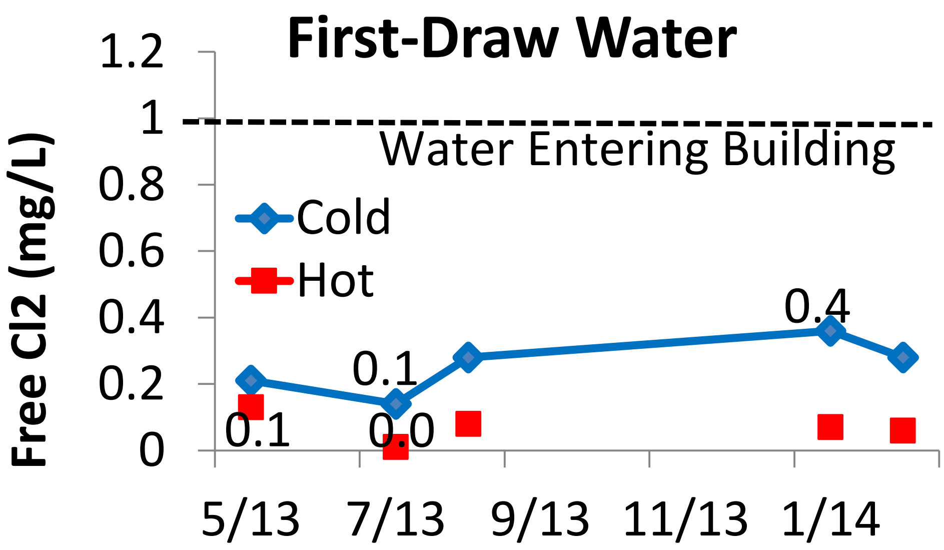
Why are high (*Legionella*-protective) temperatures not preferred?

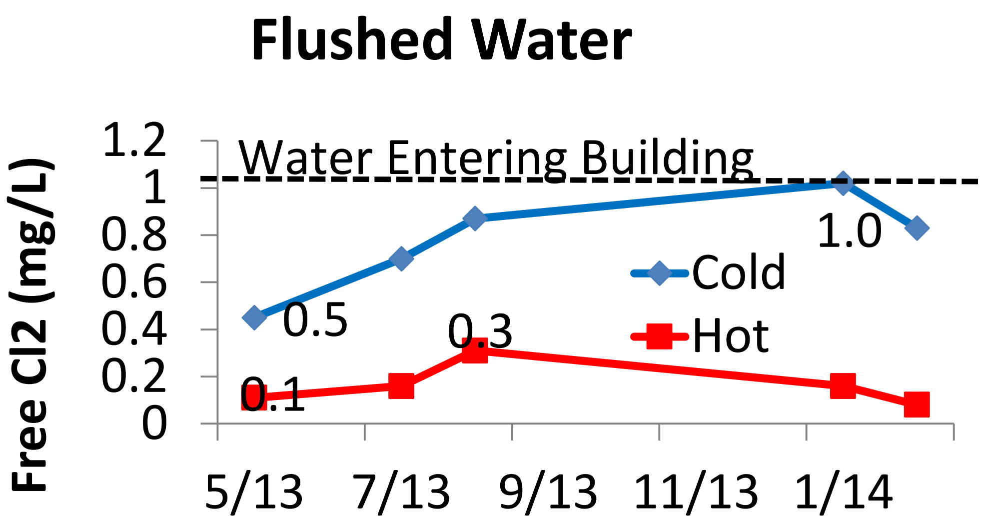


Edwards et al. 2010

How about disinfectant levels?

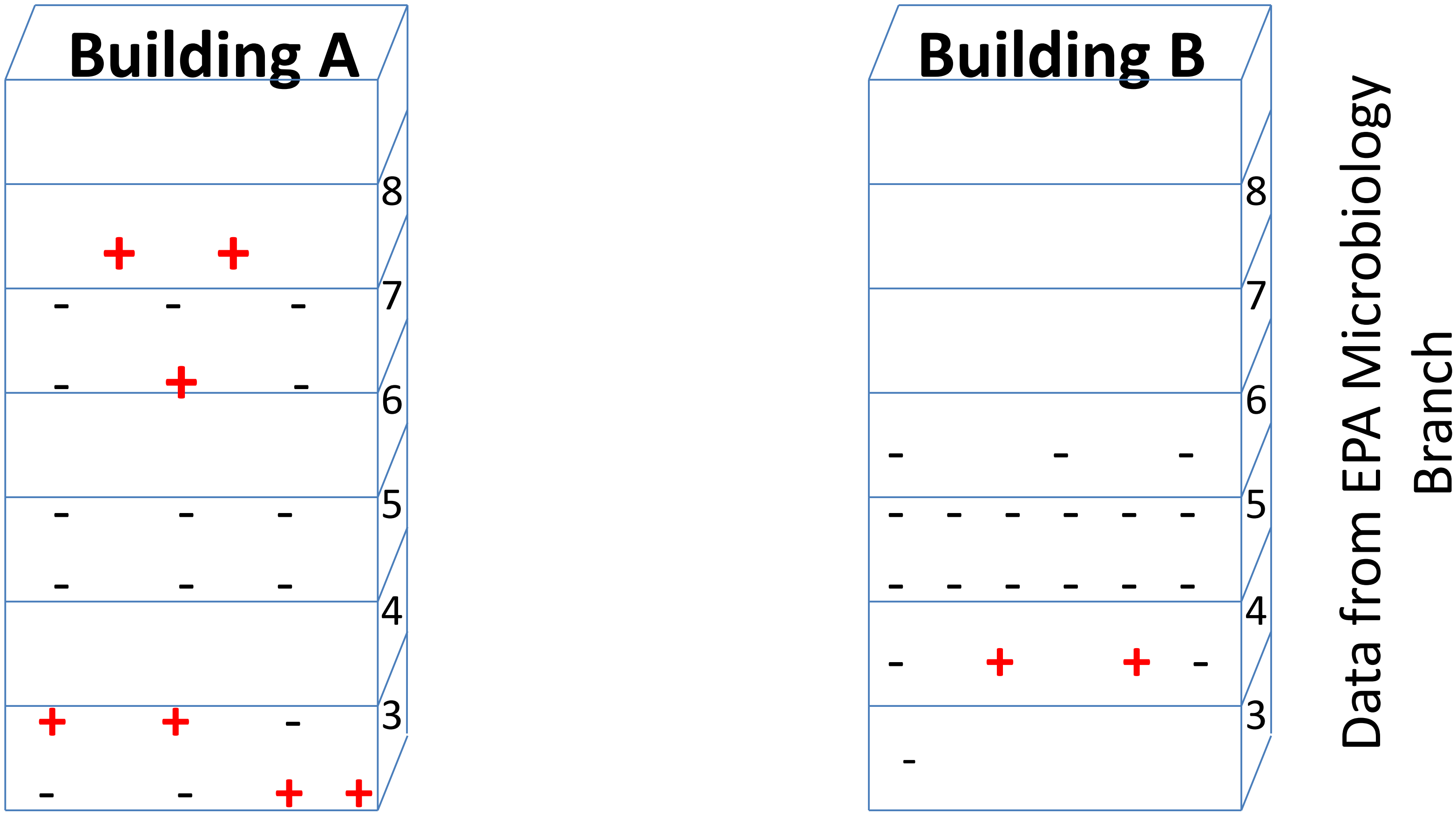
Case Study 1: Disinfectant variability





- Water entering the hospital loses much of its chlorine disinfectant within the hospital
- First-draw water has less disinfectant than flushed water
- Hot water has less disinfectant than cold water
- Are these levels sufficiently protective against pathogens?

Case Study 1: *Legionella* bacteria in showerhead biofilms



\+ means 9/40 positive *L. Pneumophila* serogroup 1 [qPCR]

\+ does not necessarily translate to disease, so how risky is it?

Many hospitals nation-wide opt to proactively control pathogens by adding “in-building” disinfection

In-building disinfection

→ Thermal disinfection

Example: ASHRAE Guideline 12-2000

- Water always stored at > 60°C in water heater
  > 51°C in hot water lines
- Different instructions after outbreaks or for periodic thermal disinfection

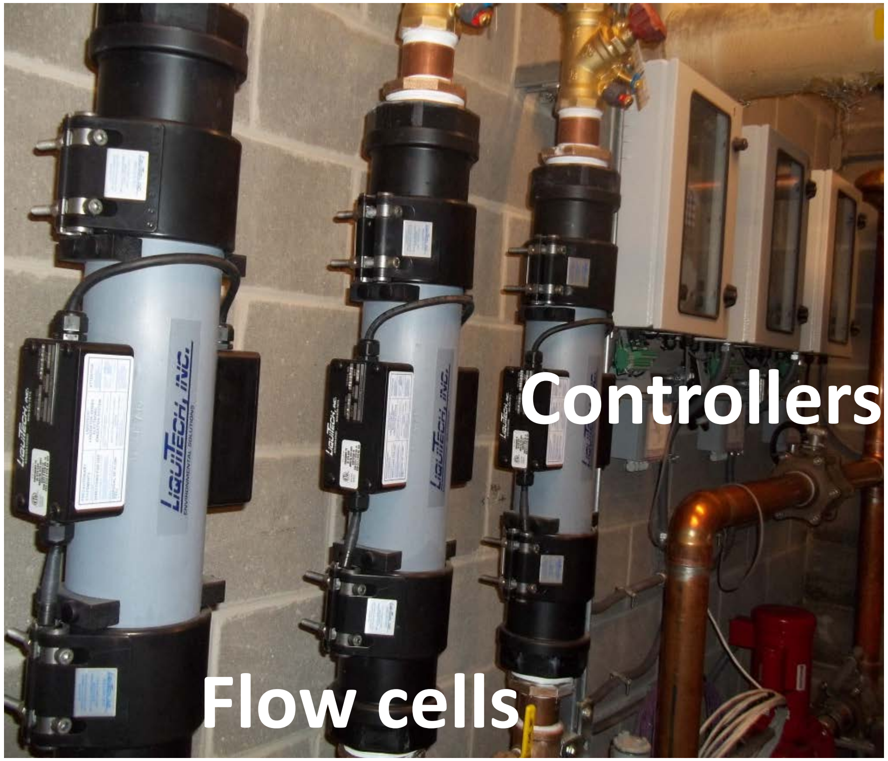
→ Chemical Disinfection

- Chlorine
- Chloramine
- Chlorine dioxide
- Copper-silver ionization
- UV irradiation
- Ozone

→ All methods have expected advantages/disadvantages

- EPA is preparing review document
- Water Research Foundation Report # 4379

Copper-Silver Ionization is one option



Inside a "Fresh" Flow cell

Good Maintenance Needed

- Adds copper (Cu) and silver (Ag) to water →biocides

Case Study 2: Hospital with copper-silver ionization in hot water to control *Legionella*

- 4 faucets
- First draw water and flushed water (1 min)
- Hot water only
- Showerheads
- Test for microbiological parameters, metallic contamination, general water chemistry
- All data from EPA MCC Branch (Microbiology)

Case Study 2: *Legionella* bacteria in showerhead biofilms

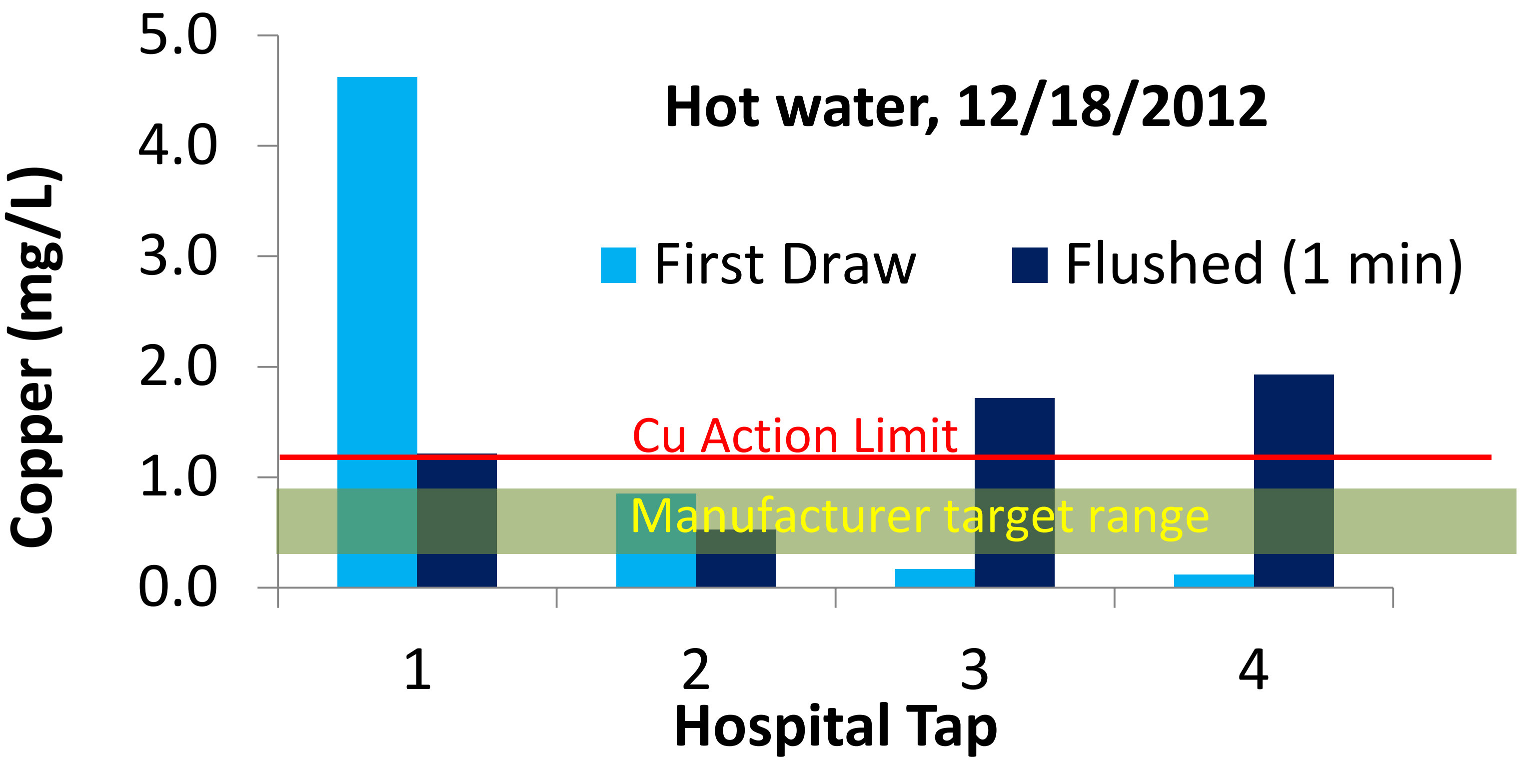
Activation of Cu/Ag unit →

Room #	June	Aug	Oct	Dec	Feb	April	June
3722	-	-	-	-	-	-	-
1607	-	-	-	-	-	-	-
A302	-	-	-	-	-	-	-
2614	+	+	-	-	-	-	-
ED 17	-	-	-	-	-	-	-
OR 10	+	-	-	-	-	-	-

+ means positive *L. Pneumophila* [by culture]

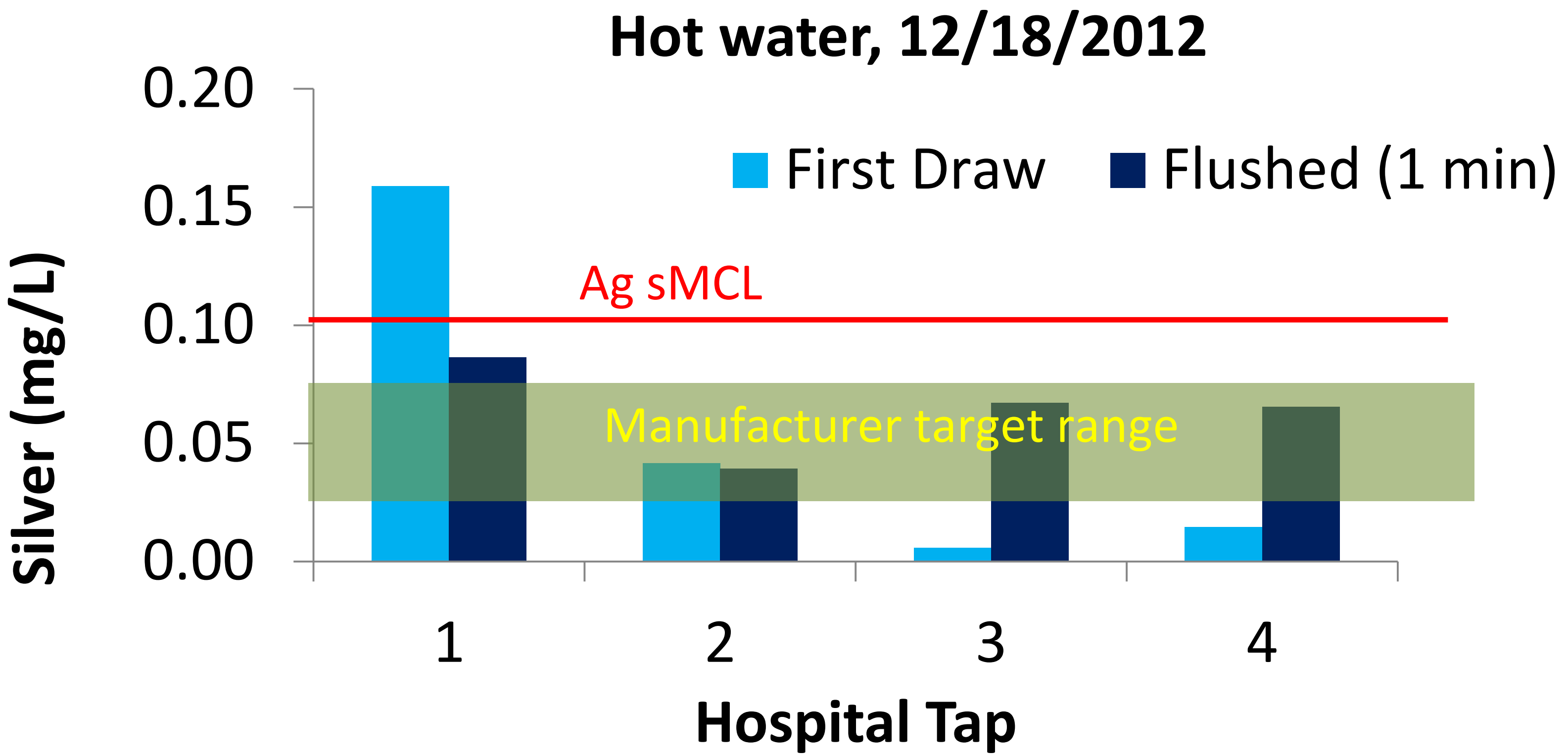
- Initial results optimistic
- Longer-term data are needed

Case Study 2: Copper in water



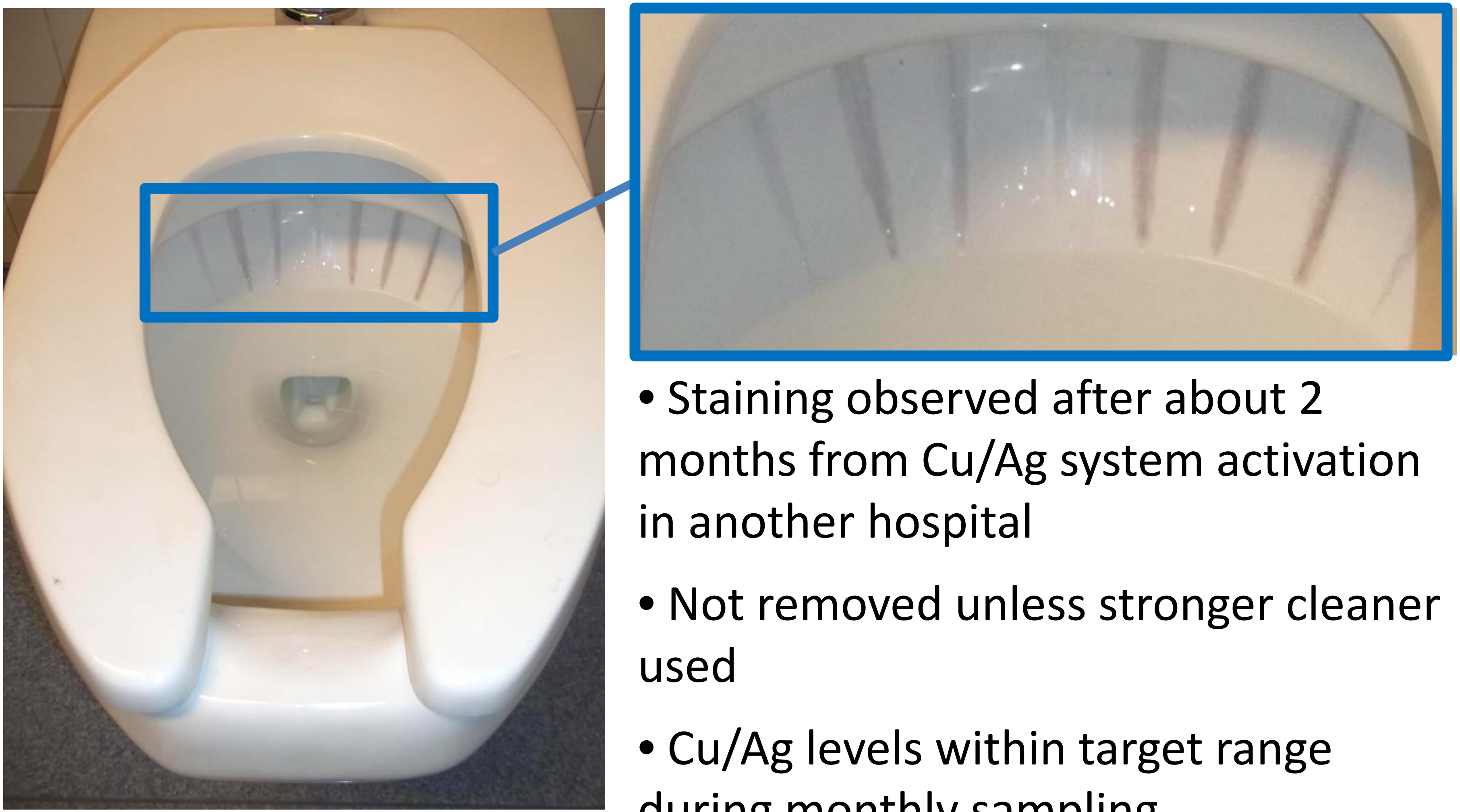
- Copper from ionization unit and from plumbing
- Copper levels variable between taps:
  - Some higher than Cu Action Limit (first-draw and flushed water)
  - Some lower than manufacturer target range in first-draw water

Case Study 2: Silver in water



- Silver from ionization unit only
- Silver levels variable between taps:
  - One tap higher than Ag secondary MCL in first-draw water
  - Some taps lower than Ag target range in first-draw water

Staining



- Staining observed after about 2 months from Cu/Ag system activation in another hospital
- Not removed unless stronger cleaner used
- Cu/Ag levels within target range during monthly sampling

In-building water treatment may alter the incoming water quality (intended and unintended)

So how should it be monitored to ensure the safety of water?

Provisions of the Safe Drinking Water Act (SDWA)

"Public water system (PWS) is a system for the provision to the public of water for human consumption through pipes or other constructed conveyances, if such system has at least fifteen service connections **or regularly serves at least twenty-five individuals**"

Provisions of the SDWA

- A public water system is not regulated when:

  → Consists only of distribution and storage facilities, **and does not have any collection and treatment facilities**

- Based on this exemption, hospitals that receive water from a PWS:

  → Are not regulated if they do not have their own additional treatment facilities

  → Are regulated if they have their own additional treatment facilities

Other large buildings could also be PWSs subject to SDWA

Public Water Systems

- **Community Water Systems**
  - Municipal systems
  - Nursing homes
  - Apartment Complexes
- **Transient Non-Community**
  - Campgrounds
  - Gas stations
- **Non-transient Non-Community**
  - Hospitals
  - Schools/daycares

Schools, nursing homes, apartment complexes, casinos/resorts, etc. that meet the PWS definition, if they add their own in-building water "treatment"

Part I Conclusions

- *Legionella* (and other opportunistic pathogens) may colonize hospital showerheads if disinfectant residual is not sufficient and if water temperature is not limiting their growth

- Variety of "in-building" disinfection methods to overcome disinfectant loss
- Many hospitals choose to proactively control possible disease outbreaks by installing these
- They may alter end drinking water and potentially affect primary or secondary drinking water contaminants

- Activation of "in-building" treatment triggers requirements to comply with the SDWA which are not always recognized/understood
- Preliminary discussions with some State representatives suggest that these requirements are interpreted differently

- EPA review document on *Legionella* control strategies

" Technologies for Legionella Control in Premise Plumbing Systems: Scientific Literature Review"

https://www.epa.gov/ground-water-and-drinking-water/technologies-legionella-control-premise-plumbing-systems

Part II: Schools

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journal homepage: www.elsevier.com/locate/scitotenv

Reduced risk estimations after remediation of lead (Pb) in drinking water at two US school districts

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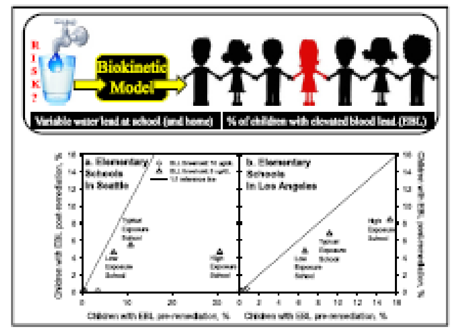
HIGHLIGHTS

- Risks after water Pb remediation at US schools were assessed for the first time.
- The entire measured water Pb distributions were input to the IEUBK model.
- The upper tail of the predicted blood Pb distribution reflects sensitive children (% at risk).
- This is a different approach from predictions of geometric mean blood Pb levels.

GRAPHICAL ABSTRACT



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Variability
Integrated Exposure Uptake Biokinetic (IEUBK) model

ABSTRACT

The risk of students to develop elevated blood lead from drinking water consumption at schools was assessed, which is a different approach from predictions of geometric mean blood lead levels. Measured water lead levels (WLLs) from 63 elementary schools in Seattle and 601 elementary schools in Los Angeles were acquired before and after voluntary remediation of water lead contamination problems. Combined exposures to measured school WLLs (first draw and flushed, 50% of water consumption) and home WLLs (50% of water consumption) were used as inputs to the Integrated Exposure Uptake Biokinetic (IEUBK) model for each school. In Seattle an average 11.2% of students were predicted to exceed a blood lead threshold of 5 μg/dL across 63 schools pre-remediation, but predicted risks at individual schools varied (7% risk of exceedance at a "low exposure school", 11% risk at a "typical exposure school", and 31% risk at a "high exposure school"). Addition of water filters and removal of lead plumbing lowered school WLL inputs to the model, and reduced the predicted risk output to 4.8% on average for Seattle elementary students across all 63 schools. The remnant post remediation risk was attributable to other assumed background lead sources in the model (air, soil, dust, diet and home WLLs), with school WLLs practically eliminated as a health threat. Los Angeles schools instead instituted a flushing program which was assumed to eliminate first draw WLLs as inputs to the model. With assumed benefits of remedial flushing, the predicted average risk of students to exceed a BLL threshold of 5 μg/dL dropped from 9.6% to 6.0% across 601 schools. In an era with increasingly stringent public health goals (e.g., reduction of blood lead safety threshold from 10 to 5 μg/dL), quantifiable health benefits to students were predicted after water lead remediation at two large US school systems.

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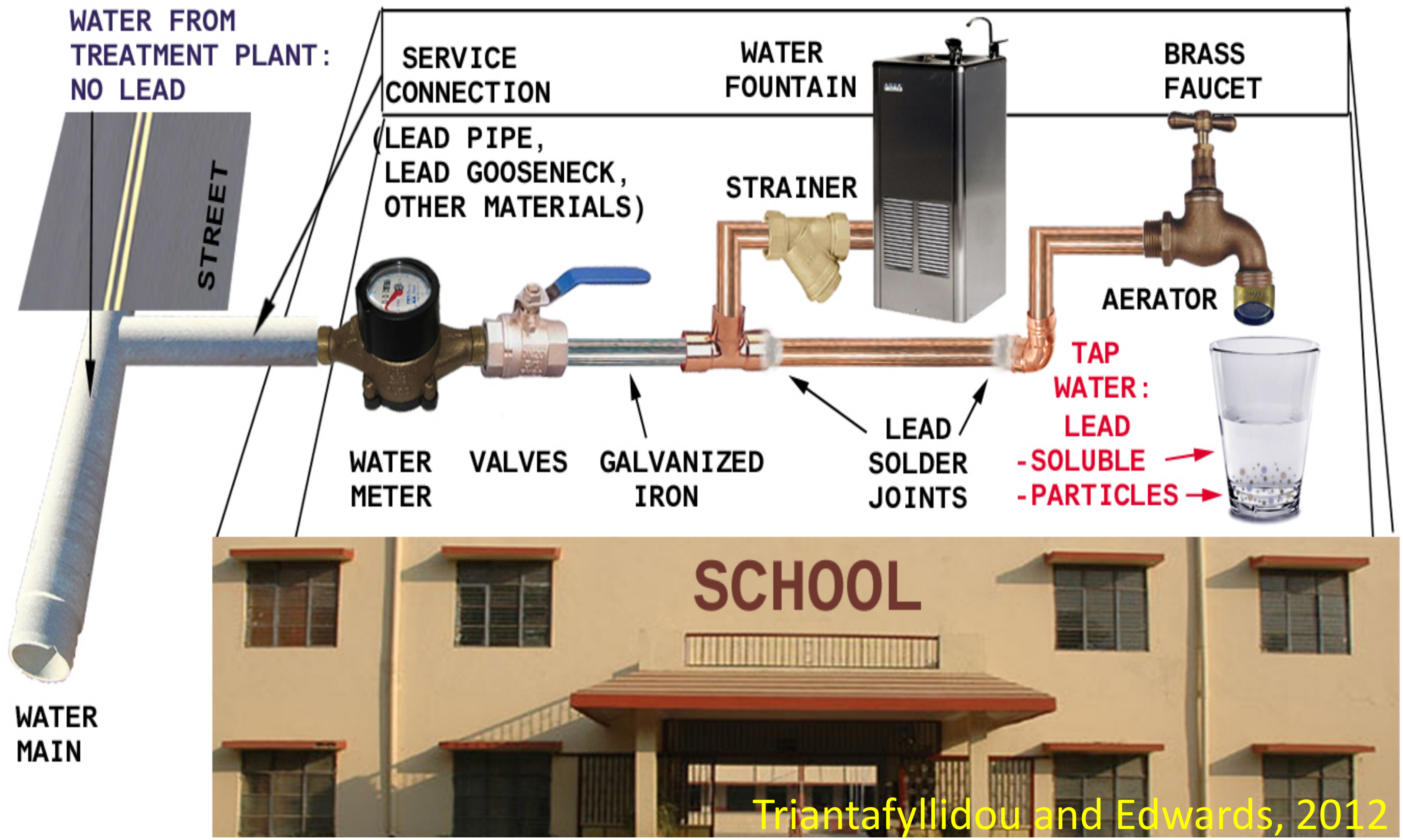
Lead (Pb) contamination of school water



–Old Lead Pipe

–Old Leaded Solder

–Leaded Brass (faucets, fittings)

*** Each school is different**

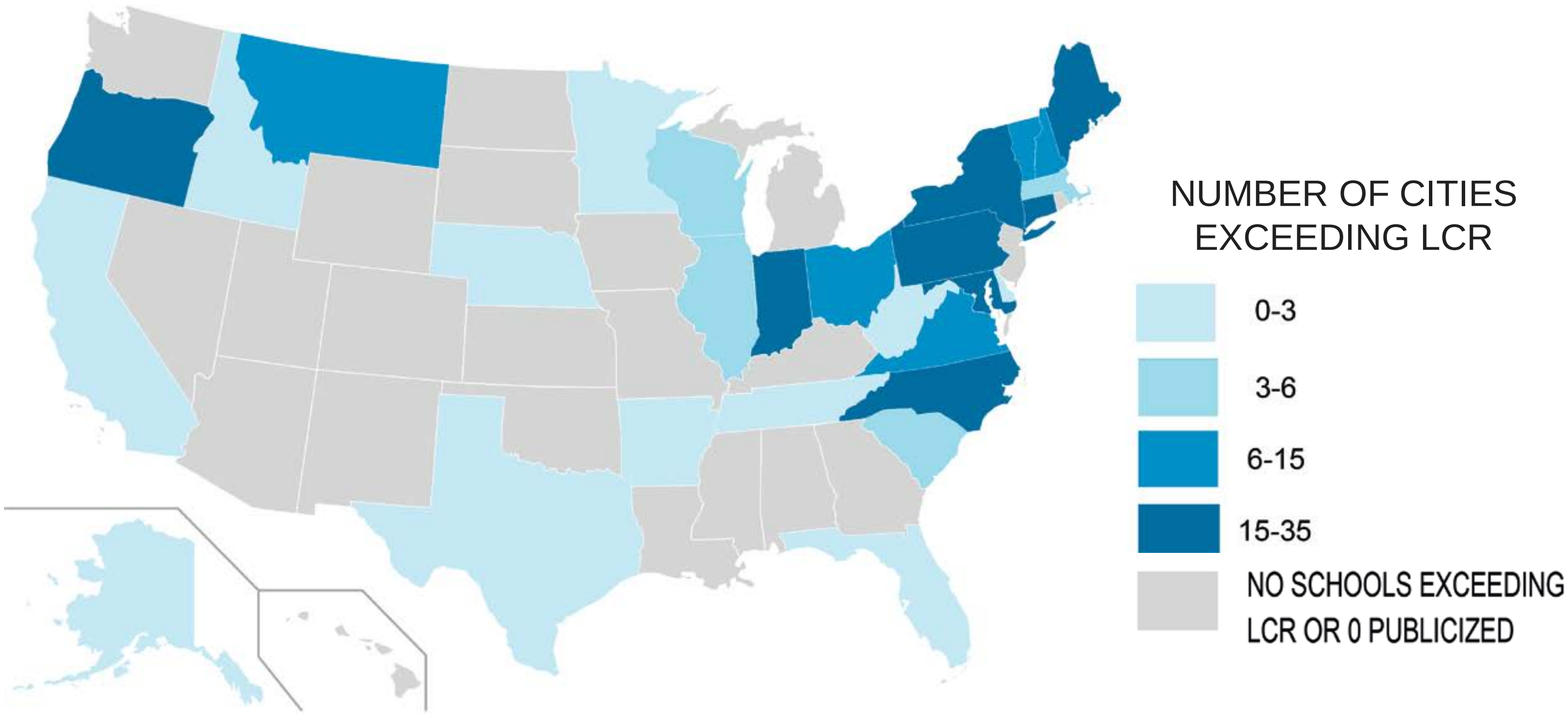
Lead in drinking water

- Lead is potent neurotoxin, no safe lead threshold established (MCLG=0)
- 20% of lead exposure attributed to drinking water in US (EPA, 2006)
- Recommended blood lead level of concern was 10 ug/dL (CDC, 2005). Reduced to 5 ug/dL (CDC, 2012)

Lead (Pb) regulations for school water

	Lead and Copper Rule (LCR)	Lead Contamination Control Act (LCCA)
Applies to	-Homes 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)
Enforceable?	Yes, federal regulation	No, voluntary guidance
Sampling Requirement	1 Liter cold water samples after at least 6 hours of stagnation	250 mL cold water samples after 8-18 hours of stagnation
Remediation criterion	Over 10% of samples exceeding "Action Limit" of 15 ug/L lead	Any water sample exceeding 20 ug/L lead
Reference	US EPA, 1991	US EPA, 2006

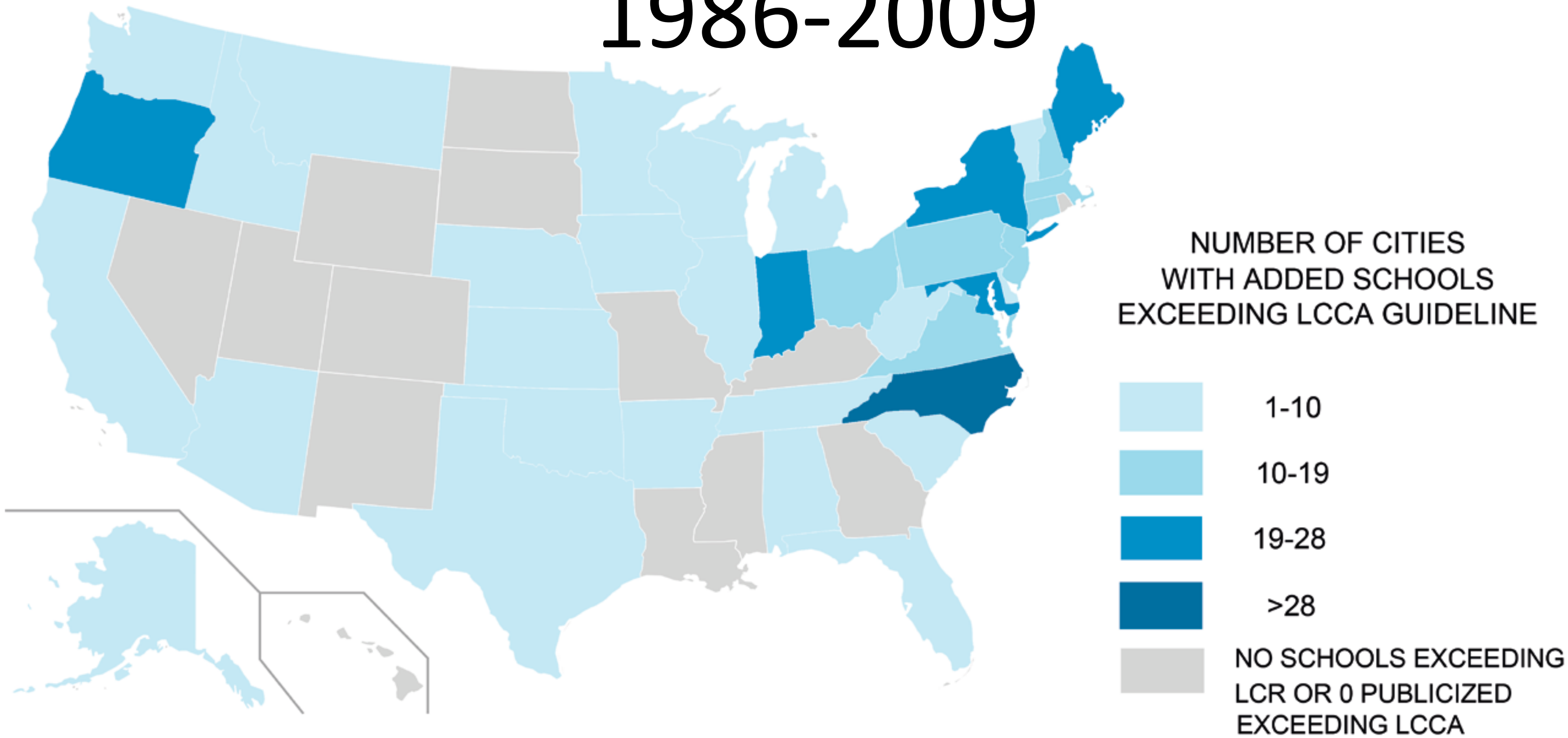
Number of cities with schools that exceeded LCR at least once, 1998-2008



- Refers to 10% of US schools that fall under LCR and are required to conduct/report LCR sampling
- Thematic map constructed from US EPA database as reported by Burke (2009)

Credit: Triantafyllidou, Lambrinidou and Edwards 2012

Number of cities with additional schools that exceeded LCCA at least once, 1986-2009



- Refers to 10% of US schools that fall under LCR, and
- 90% of US schools that fall under LCCA and are not required to conduct/report sampling results (peer-reviewed literature and newspapers)

Credit: Triantafyllidou, Lambrinidou and Edwards 2012

Overall, an estimated 35+ States and the District of Columbia had schools with high lead in water at least once during 1986-2009

*States shaded grey in thematic map mostly reflect no available information

Case Study 3: Elementary schools Within a School District

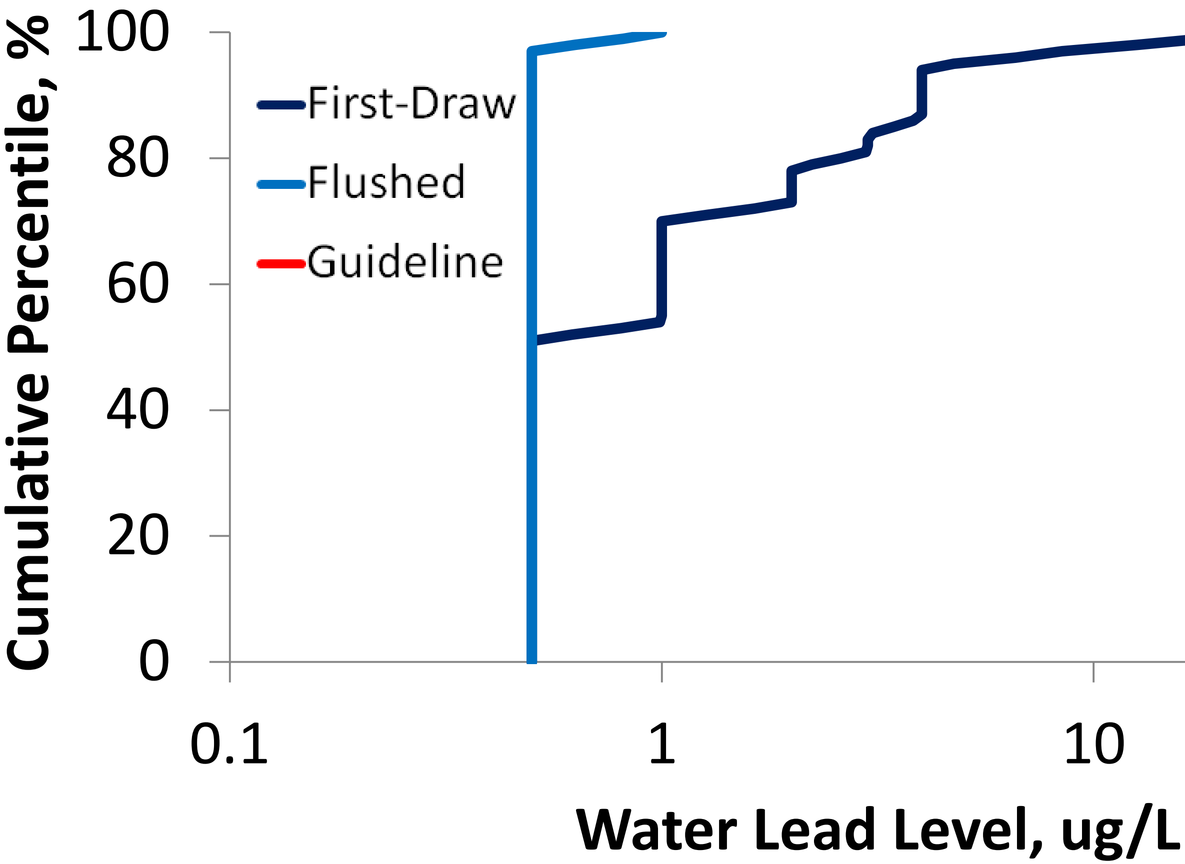
- Schools receive water from local water utility
- As such, water sampling for lead (Pb) is not required
- Local Water Utility responsible to comply with LCR action limit for lead, and has been continuously in compliance
- Schools could voluntarily test for lead according to LCCA (voluntary guideline of 20 ug/L)
- After parental complaints, schools voluntarily tested for lead in water

Case Study 3: Elementary schools Within a School District

- Lead concentrations in water publicly available (website) from all fountains/faucets at 71 elementary schools in school district
- 250 mL of cold water sampled from each fountain/faucet
- First draw and flushed water (30 seconds)
- Results before voluntary remediation
- Lead levels have since dropped

Case Study 3: Elementary schools Within a School District

"Low Exposure" School, N=19

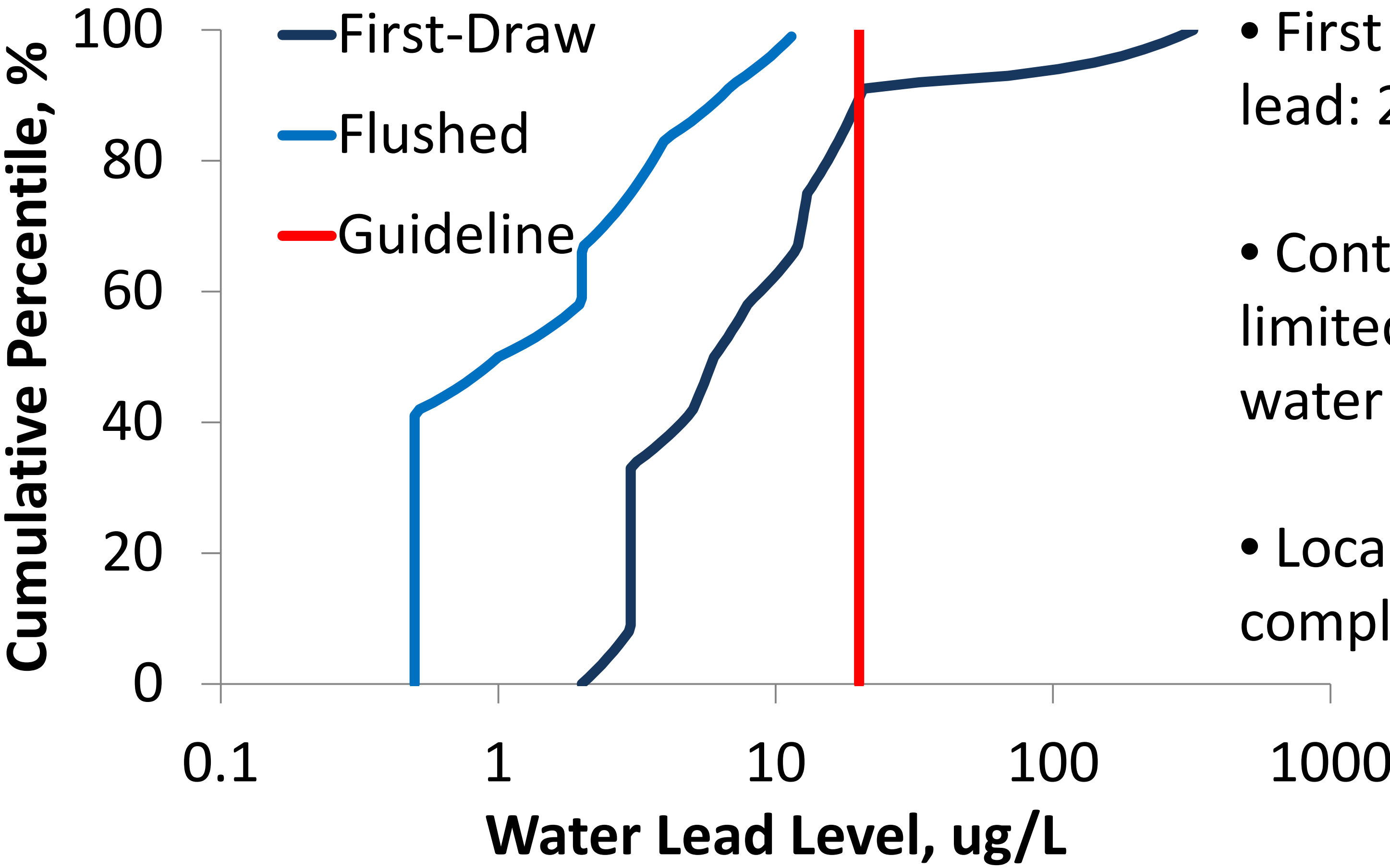


- First Draw water lead: <1-23 µg/L
- Lead consistently below 20 µg/L with one exception
- Local water utility consistently compliant with LCR

Triantafyllidou et al., 2013

Case Study 3: Elementary schools Within a School District

"Typical Exposure" School, N=38

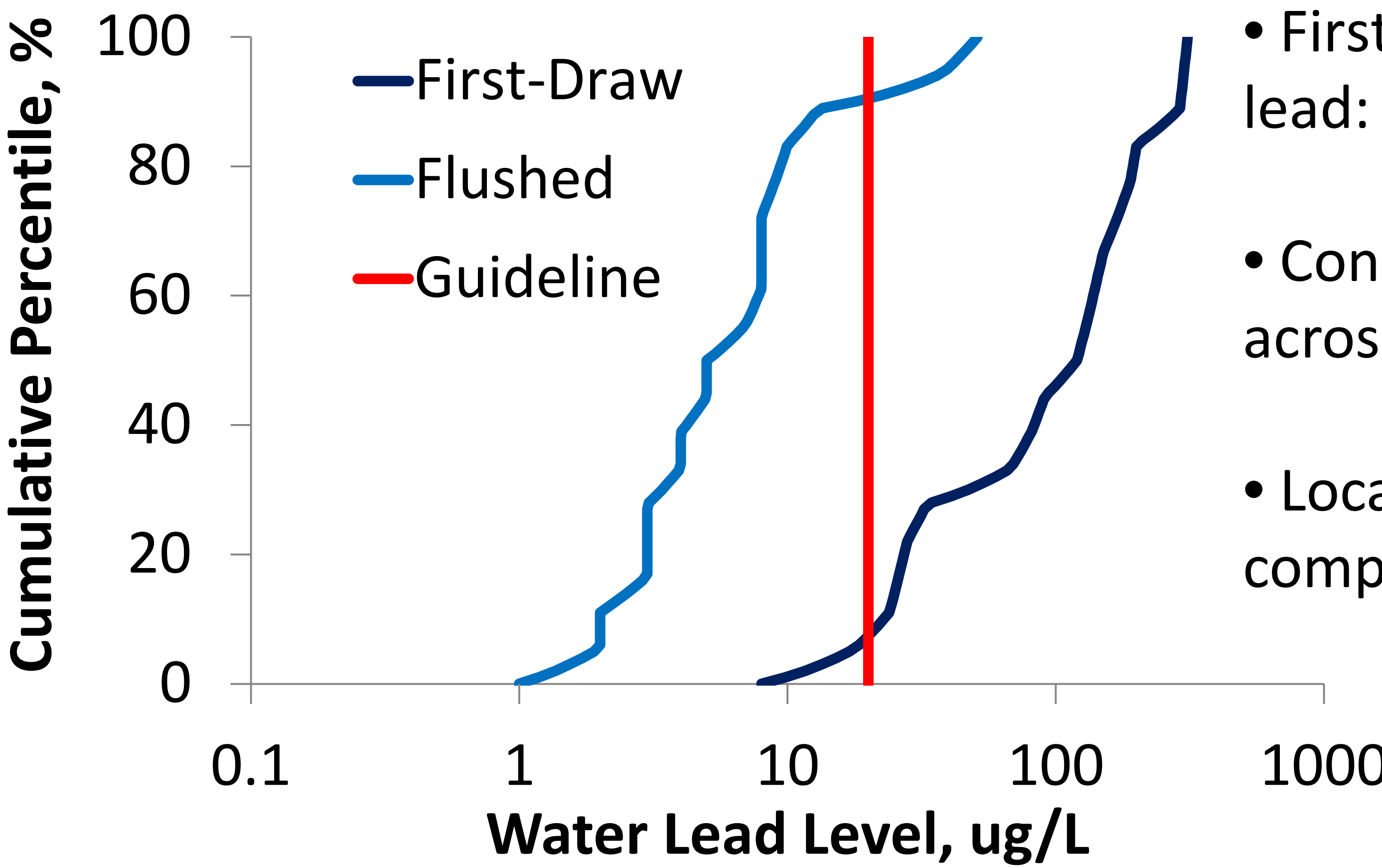


- First Draw water lead: 2-320 µg/L
- Contamination limited to certain water fountains
- Local water utility compliant with LCR

Triantafyllidou et al., 2013

Case Study 3: Elementary schools Within a School District

"High Exposure" School, N = 13



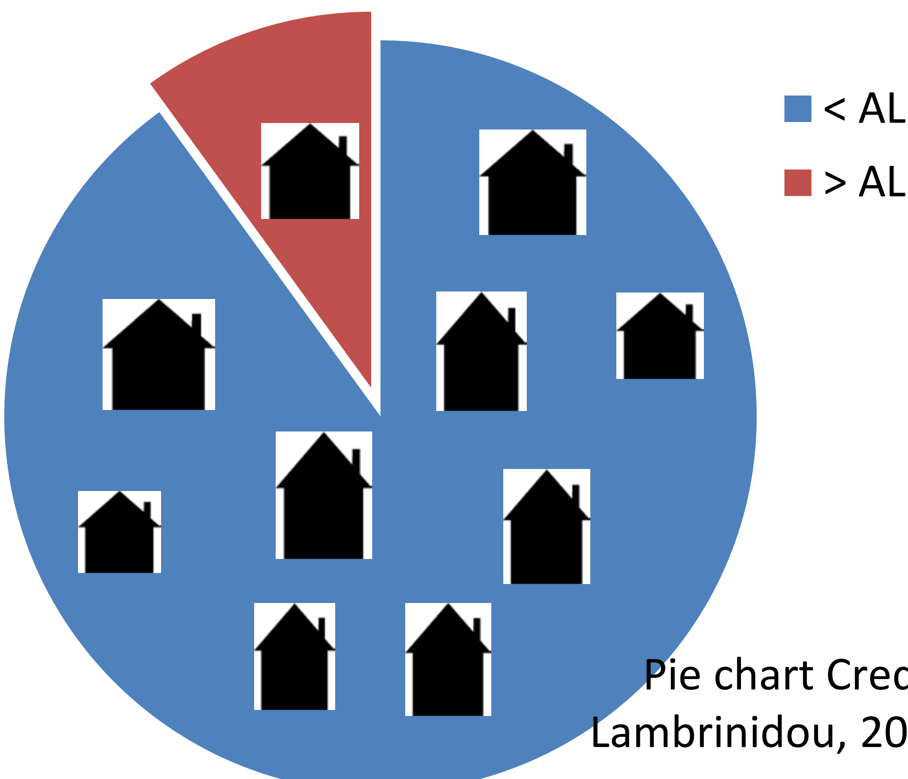
- First Draw water lead: 8-310 µg/L
- Consistently high across School
- Local water utility compliant with LCR

Triantafyllidou et al., 2013

Intent of the LCR

- The lead AL does not determine the compliance status of a system as does an MCL, but serves as a surrogate for a detailed optimization demonstration (US EPA, 1991)

- Aimed at identifying system-wide problems rather than problems at outlets in individual buildings (US EPA, 2006)



AL≠ MCL

Pie chart Credit:
Lambrinidou, 2010

Schools are different from homes

- Many built before the lead ban of 1986 (similar to older homes)
- Large buildings with complicated plumbing lines
- Water use patterns can be “worst-case” for lead release after prolonged water stagnation overnight, over the weekend or over summer break

Part II Conclusions

- Variability in water lead contamination among schools receiving the same water

- Variability among fountains within a school

- Schools may have “hazardous” fountains even if local water utility complies with LCR

LCR ✓

LCCA X

- Lead contamination at schools needs to be identified and remediated on CASE-BY-CASE basis

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Useful Reading

- National Academy of Sciences, 2006. Drinking Water Distribution Systems: Assessing and Reducing Risks. Chapter 8 on *Alternatives for Premise Plumbing*. Accessible at http://www.kysq.org/docs/DWDS_NAS.pdf
- Pruden et al, 2013. State of the Science and Research Needs for Opportunistic Pathogens in Premise Plumbing. Water Research Foundation Report #4379. Accessible at http://www.waterrf.org/Pages/Projects.aspx?PID=4379
- Burke, G, 2009. School drinking water contains toxins. Associated Press. Relevant interactive school map at http://hosted.ap.org/specials/interactives/_national/toxic_water/?SITE=CODEN&SECTION=HOME
- Triantafyllidou, S., Lytle, D., Muhlen, C. Copper-Silver Ionization at a US Hospital: Interaction of Treated Drinking Water with Plumbing Materials, Aesthetics and Other Considerations, *Water Research*, 02:1-1011-1021, 2016
- Triantafyllidou et al, 2014. Reduced Risk Estimations After Remediation of Lead (Pb) in Drinking Water at Two US School Districts. *Science of the Total Environment* 466–467:1011-1021

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