Case Study of Microbial Growth in New Buildings with Water Conservation Features

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California Energy Commission
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3rd International Conference on Sustainability Engineering and Science

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

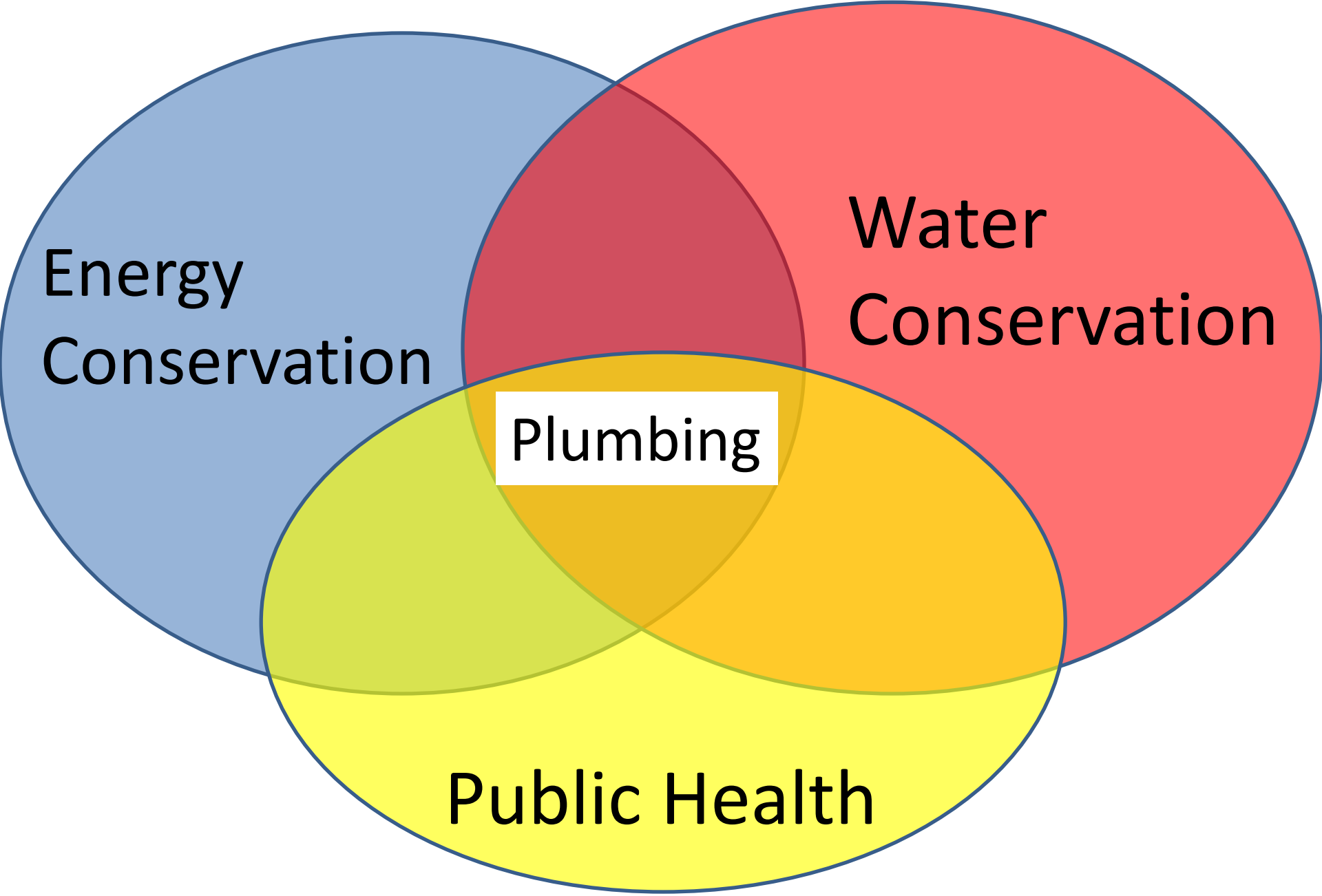
- Surveillance for Waterborne Disease Outbreaks Associated with Drinking Water and Other Nonrecreational Water — United States, 2009-2010
- **September 6, 2013 / 62(35);714-720**

Despite advances in water management and sanitation, waterborne disease outbreaks continue to occur in the United States.

……..*Legionella* accounted for 58% of outbreaks 93% of deaths

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

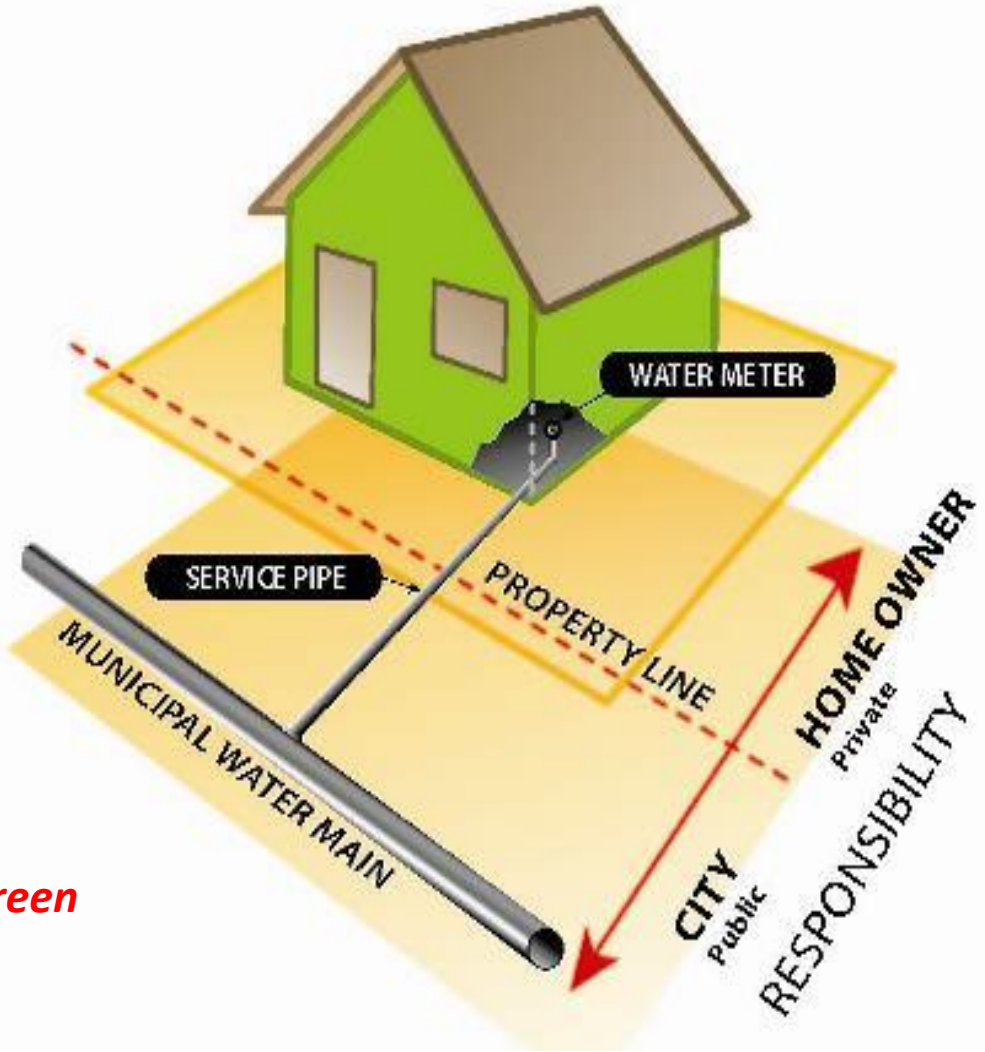
Virginia Tech



Co-authors Dr. Amy Pruden, William Rhoads, Kathita Chittaladakorn

General Characteristics of Premise Plumbing

- Long detention time
- Low disinfectant residuals
- Warmer temperatures
- Varied materials
- Large diurnal variation in flow



Changes in Regulation, Flow Patterns in Green Construction, and Improved Awareness of Waterborne Disease

Image: Randi Brazeau, Sheldon Masters

Highlights of:

- Unleaded Brass Performance Research
- Hex Chrome Cr(VI) Issue
- LEED (Building Water Quality)
- Legionella
- Changes in Water Chemistry

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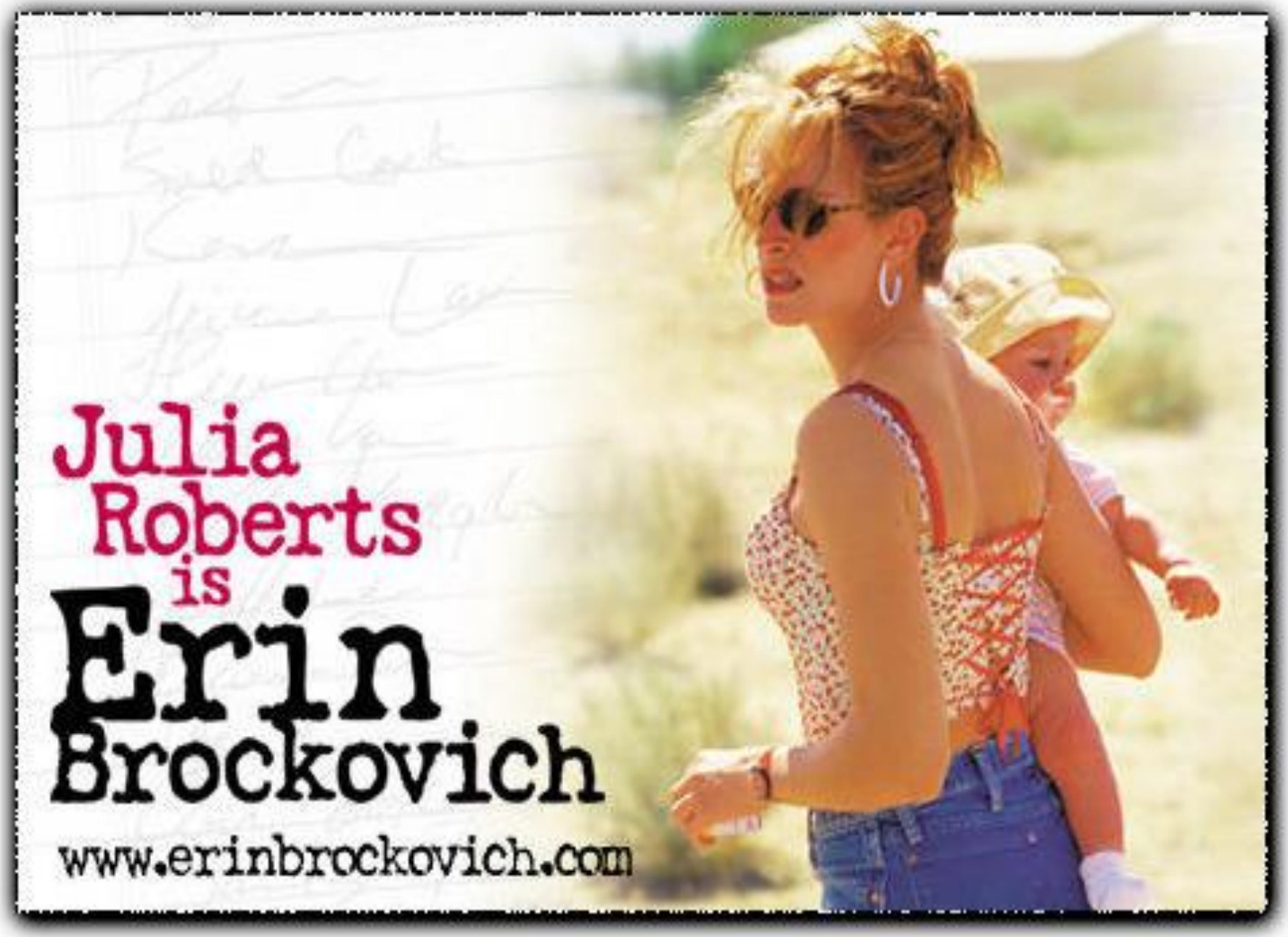

Julia
Roberts
is
Erin
Brockovich
www.erinbrockovich.com

Why Cr(VI)?

(Reduced)

Cr(I

(Oxidized)

(VI)

Micronu

d carcinogen in

king water

Public Health Goal 0.02 ppb

	Current Standard [Cr(III)+Cr(VI)]	Proposed Standard [Cr(VI)]
US EPA	100 ppb	?
California	50 ppb	**10 ppb**

20 Conditions (5 x 2 x 2)

Grade	Disinfectant (MRDL)	pH

316

316L

304

304L

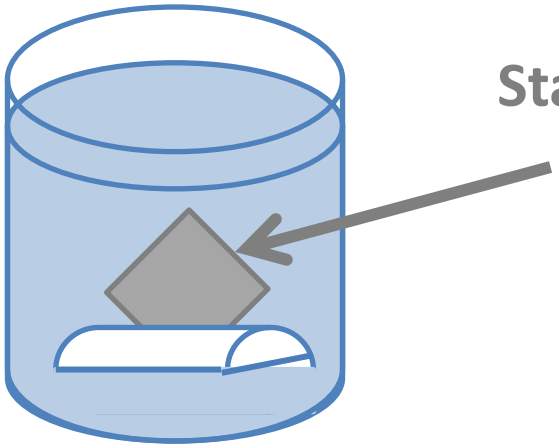
2205

Chlorine: 4 mg/L

ClO_2: 0.8 mg/L

6.5

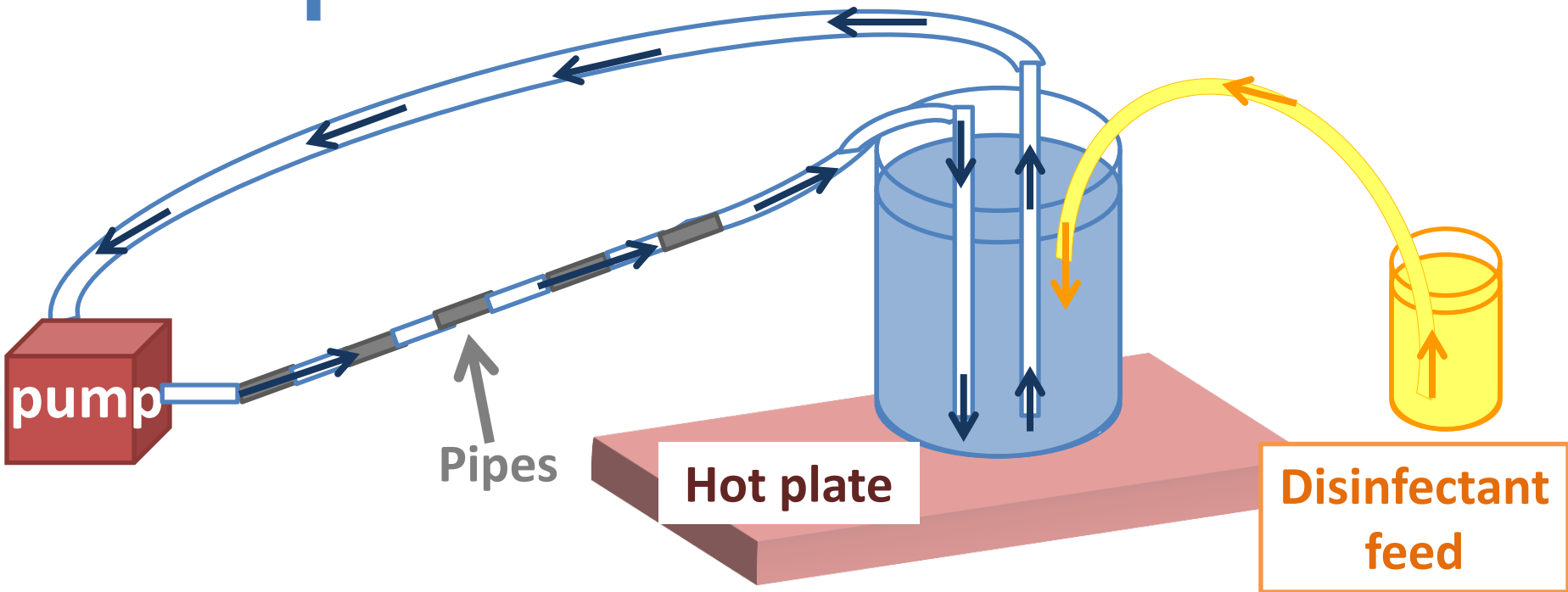
9.5



Cr(VI) Exceeded 10 ppb in just a few hours!

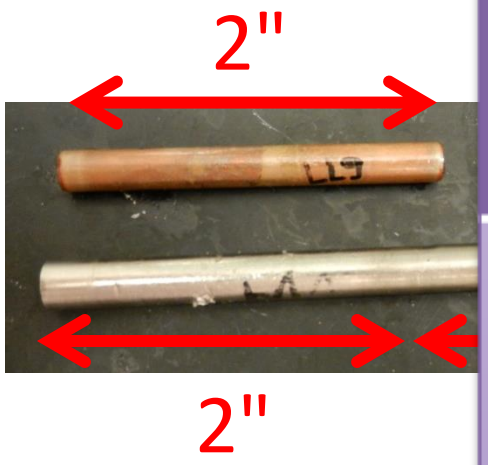
Mini Pipe Flow Systems

Metal		Copper (Control)		304 Stainless Steel
Disinfectant (MRDL)	None (Control)	Chlorine 4 mg/L	Chloramine 4 mg/L	ClO_2 0.8 mg/L



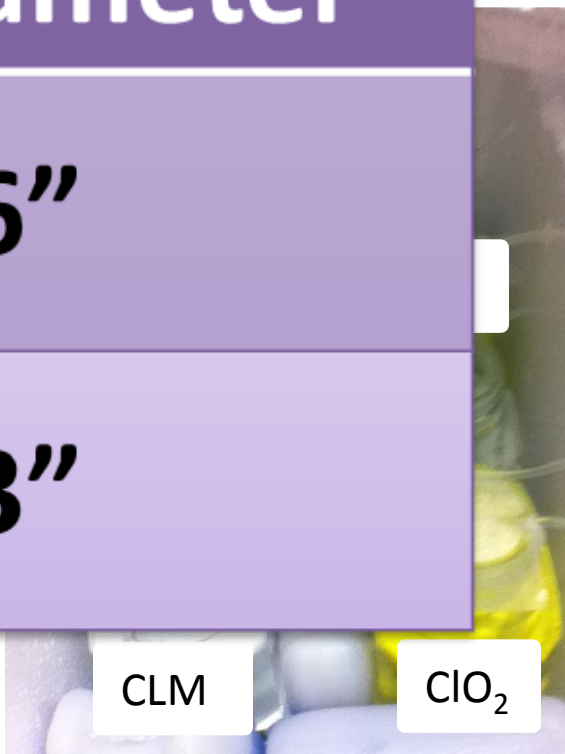
Mini Pipe Flow System

Copper: 2", 9x

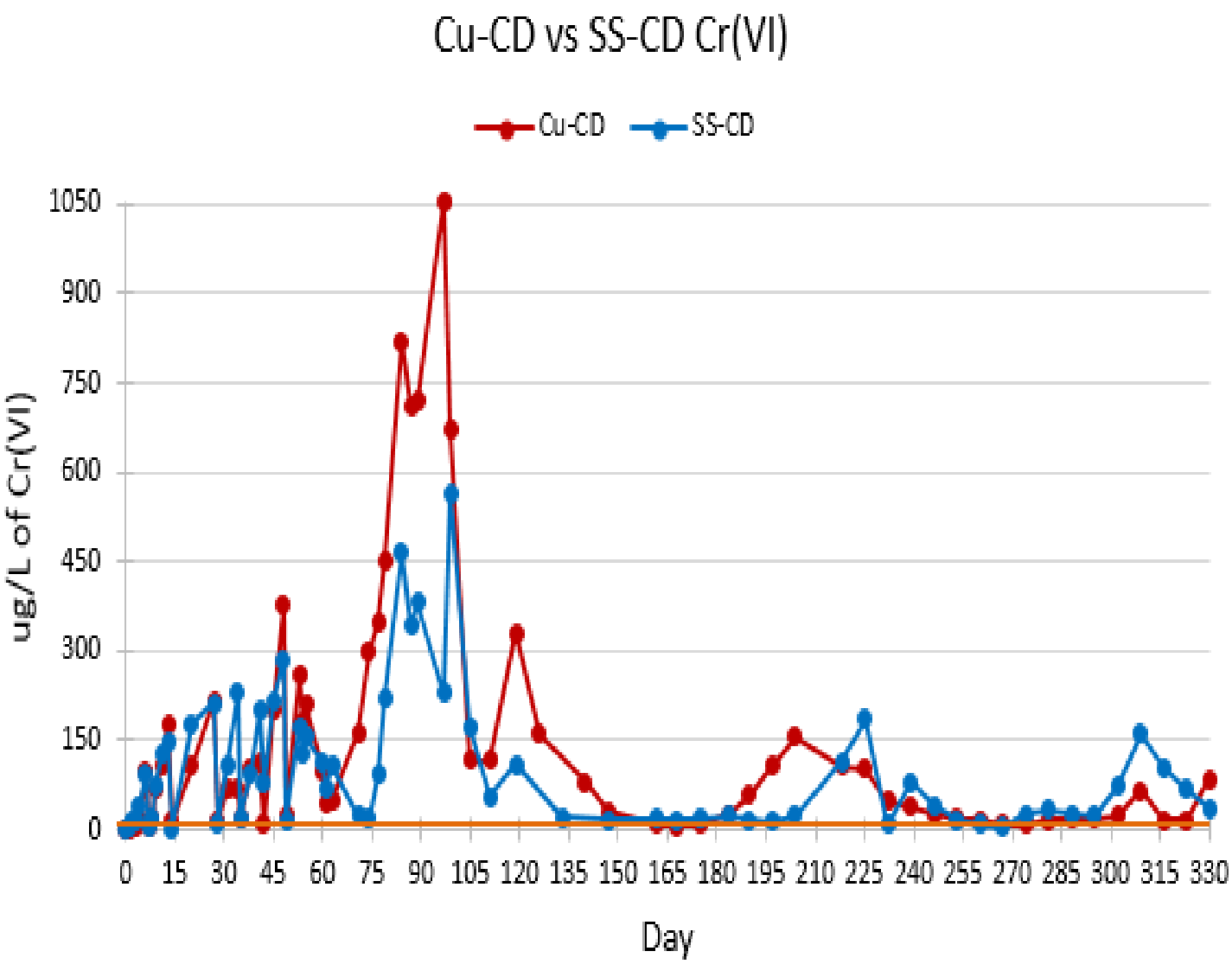


Stainless steel:
(2" welded tog

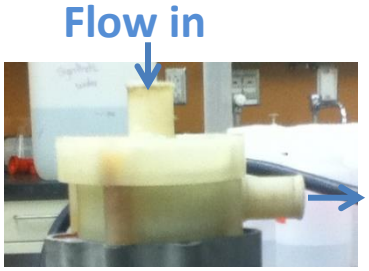
	Equivalence Pipe Diameter
Cu	8.6”
SS	4.3”

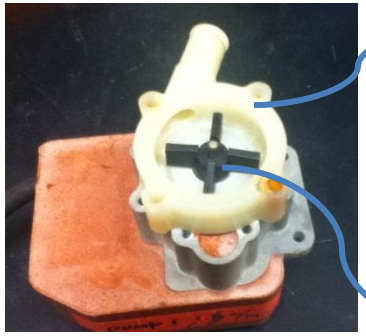


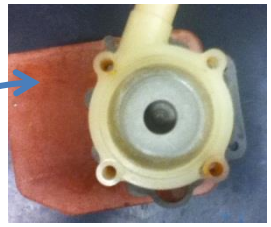
Chlorine Dioxide (or chlorine)

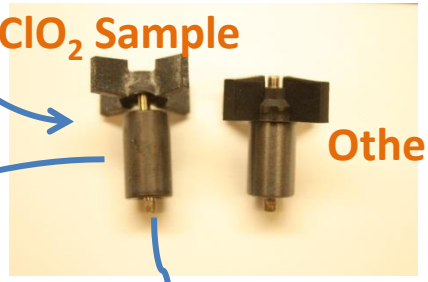


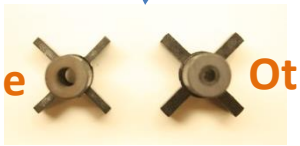
Copper Pipe with Chlorine Dioxide

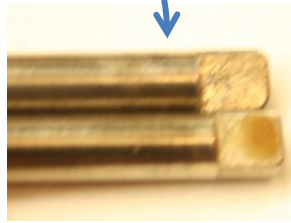












316 Stainless Steel
(16% Cr)

Conclusion

- More than 10 ppb Cr(VI) can be formed after 8 hours exposure to stainless steel at 24.5°C in batch reactors (equivalent to 6.5 in pipe)
- Cr(VI) can be formed at concentrations up to 1000 ppb in small scale premise plumbing system at 60°C
- Even small amounts of stainless steel can be a source of significant Cr(VI)
- EPA point of compliance is proposed at treatment plant!

Highlights of:

- Unleaded Brass Performance Research
- Hex Chrome Cr(VI) Issue
- LEED (Building Water Quality)
- Legionella
- Changes in Water Chemistry

SURVEY OF GREEN BUILDING WATER QUALITY: IDENTIFYING PUBLIC HEALTH AND AESTHETIC CONCERNS

William Rhoads

Marc Edwards

Water Research Foundation℠

What's different about green water systems?

- Water Age: The amount of time that passes from the time the water enters a system to the time it is used
  - Does water have an expiration date?

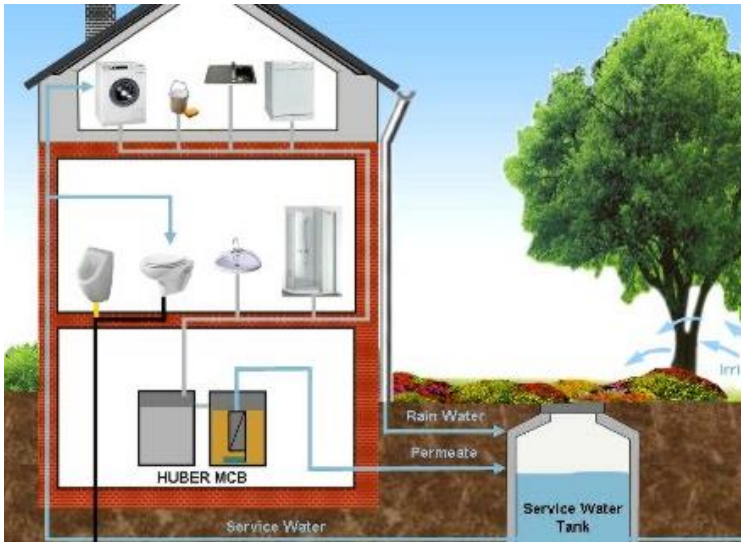
- On-site Treatment/New Sources of Potable Water

Problems Associated with Water Age

- Taste and Odor
- Maintaining Chlorine Residuals
- Opportunistic Pathogen Growth/Legionella
- Copper and Lead Corrosion

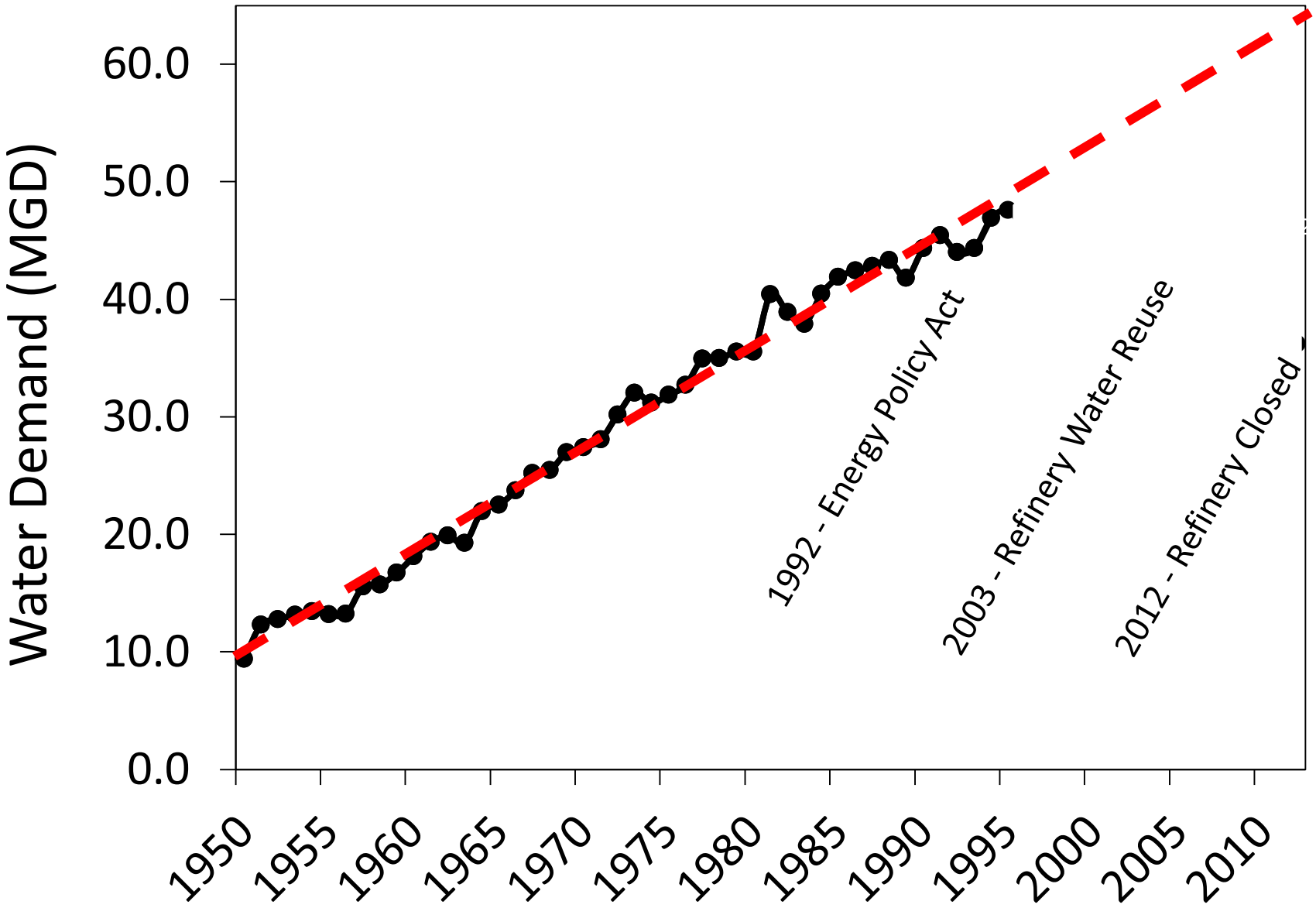
How do green systems increase water age?

- Water Conservation
  - Campaigns
  - Metered and sensor faucets
  - Low-flow showerheads and taps
  - Dual flush, or compost toilets
  - Grey water reuse
  - Black water treatment and reuse
- Water Storage
  - Rainwater collection
  - Solar “pre-heat”



www.airdelights.com; Amazon.com;
blog.oyster.com
www.buildingwithawareness.com;
http://reuseofwaterandrestrictions.weebly.com/gallery.html;
www.tamarac.org

Water Demand – Newport News Waterworks



Data: Brian Ramaley and Newport News, VA Waterworks

Simple Arithmetic

- Savings in each individual building
- Increased water age in distribution system

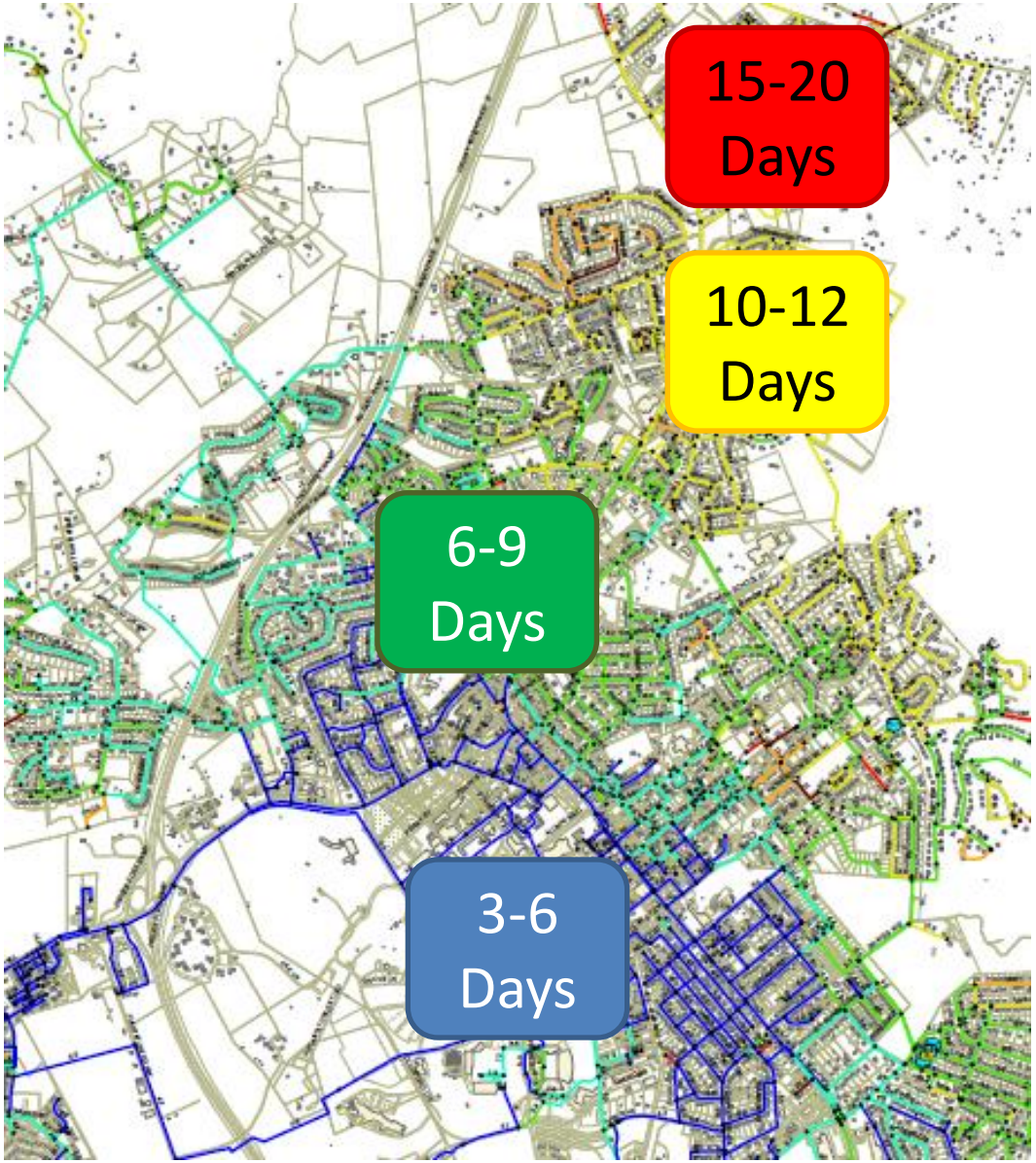
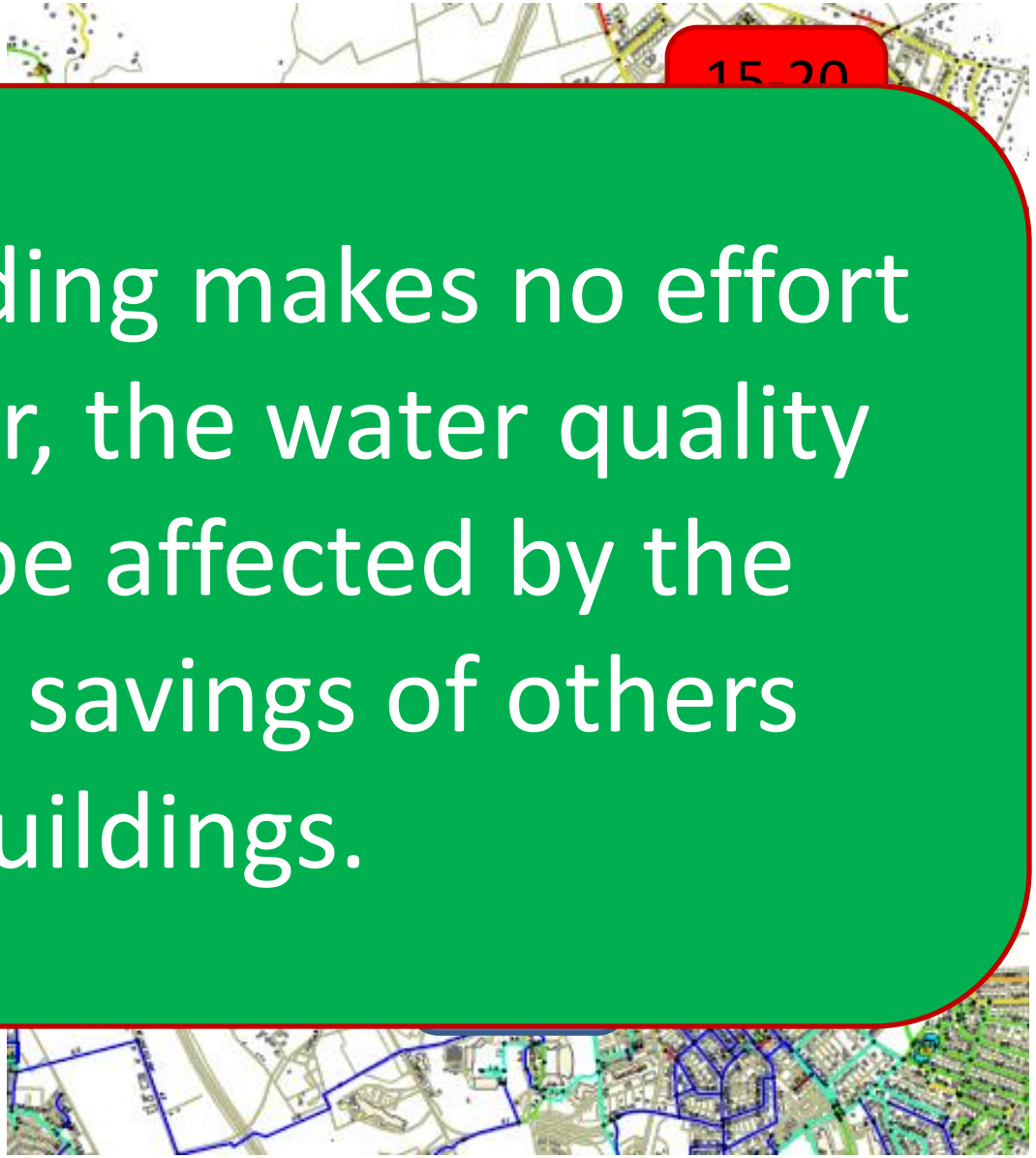


Image: Sheldon Masters and Hong Wang

Simple Arithmetic



Even if a building makes no effort to save water, the water quality could still be affected by the cumulative savings of others buildings.

Image: Sheldon Masters and Hong Wang

The Triple Conservation Condundrum

- Older water age coming into buildings
- Older water age within buildings
- Water storage with new water sources

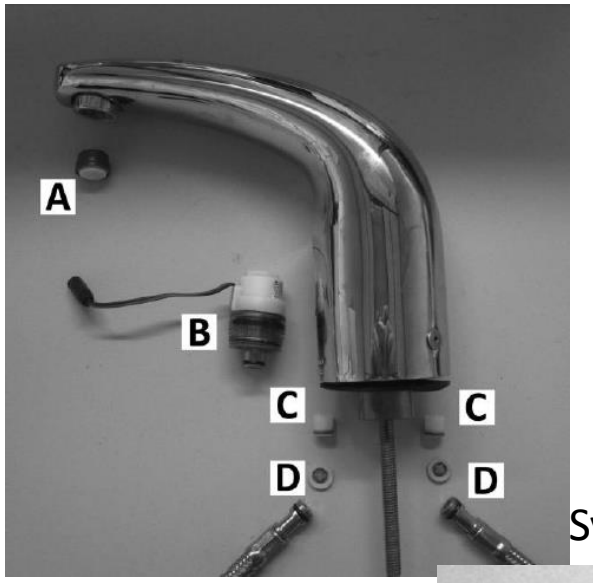
Water Age – Low Flow

- UNC
  - Uses 3-5X less water

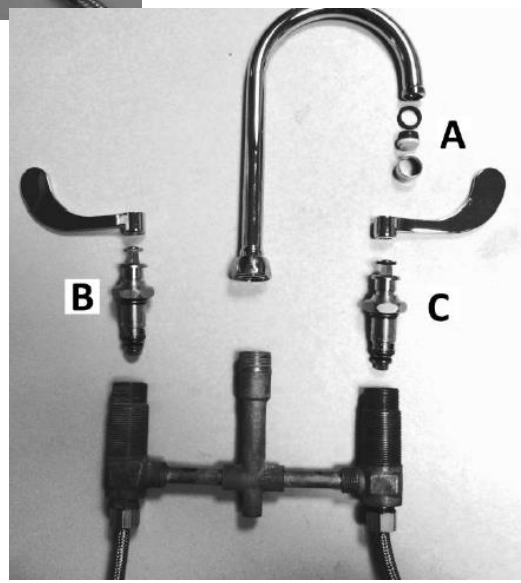
Green Plumbing Devices?	Average potable water use (gal/ft^2/month)
No	63
Yes	26
No	10
Yes; non-potable for toilets	2

Legionella Proliferation in Green Devices?

- Lower flow
- Low pressure
- Pipe materials
- Temperature
- Magnetic mixing value



Sydnor et al. 2012



Sydnor et al. 2012

However, we found that nontouch electronic faucets were more likely to become contaminated with bacteria, including *L. pneumophila*, than manually operated faucets. We also found a trend toward continued higher rates of bacterial contamination of electronic faucets after chlorine dioxide remediation, suggesting that electronic faucets may be more difficult to disinfect with standard procedures. All electronic faucet internal components tested in this evaluation grew *L. pneumophila*, with some components showing continued growth of *L. pneumophila* after chlorine dioxide remediation.

Anonymous

- Net-zero energy
- Water Age – Storage
  - Solar pre-heat hot water system

400% increase in water age without “green” devices

Net Zero Energy/Net Zero Water

- Water Age – Rain Storage, Low flow fixtures, composting toilets

- 3,000 gal rainwater cistern
  - Automatically circulates water
  - GAC + UV treatment (+1 µm filter for potable water)

Very High Legionella Species Concentration

Conclusion…?

- Need better understanding of water age
  - Pipe sizing may need to be reduced to reduce storage times
  - Hot water system designs are problematic

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- Hex Chrome Cr(VI) Issue
- LEED (Building Water Quality)
- Legionella (OPPPs)
- Changes in Water Chemistry

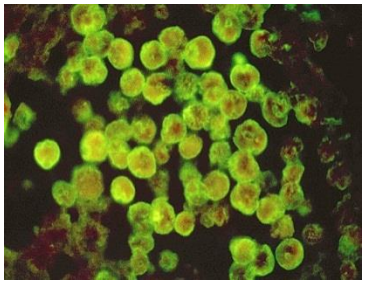
Project 4379:
Research Needs for Opportunistic Pathogens in Premise Plumbing: Experimental Methodology, Microbial Ecology and Epidemiology

Overview of Project, Drivers for Research and Outcomes

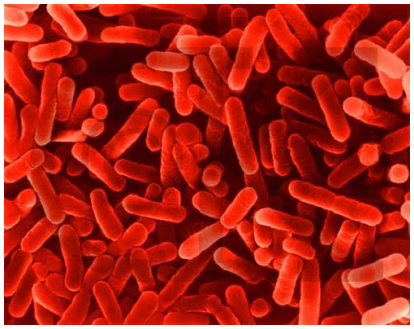
Marc Edwards, Amy Pruden (PI), Joe Falkingham

Opportunistic Pathogens

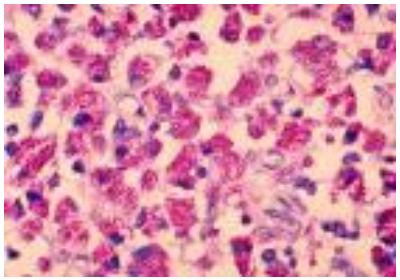
- Opportunistic pathogens in premise plumbing are now the primary source of water-borne infectious disease in developed countries
  - Per year: Up to 18,000 Legionnaire's and 30,000 MAC cases
- not fecal-associated
- Immunocompromised people particularly at risk
- Regulatory challenge- who's responsibility?



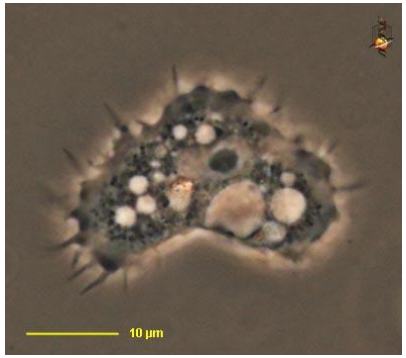
N. fowleri



L.pneumophila



Mycobacterium avium complex (MAC)



Acanthamoeba

P.aeruginosa

VirginiaTech
Invent the Future

Pathogens of Concern

Pathogen	Disease(s)	Host Organism Required?	Mode of Exposure
Legionella pneumophila	Legionnaires' disease or Pontiac fever in children	Yes	Inhalation or aspiration
Pseudomonas aeruginosa	Urinary tract infections, respiratory infections, dermatitis, soft tissue infections, bacteremia, bone and joint infections, GI infections	No	Wound infection; other modes of transmission are unknown
Mycobacterium avium	Pulmonary disease, cervical lymphadenitis (children)	No	Inhalation or aspiration
Acanthamoeba	Acanthamoeba keratitis	No	Wound infection
Naegleria fowleri	Primary amebic meningoencephalitis	No	Nasal aspiration

Opportunistic Premise Plumbing Pathogens

"OPPPs" or "OPPPs"

Practical Drivers and Opportunities

- Increased reporting/detection
- Increased susceptible populations

- Main water distribution system upgrades
- Premise plumbing upgrades
- Green building/green devices
- Energy sustainability links

These are profoundly impacting waterborne disease …

Why *Legionella*?

- Legionnaires' disease (LD)
  - 8,000-18,000 people infected each year[1,3]
  - 5-30% mortality rate[1];
  - >40% mortality rate for immunocompromised[2]
- Pontiac Fever
  - Infects 95% of people exposed[4]

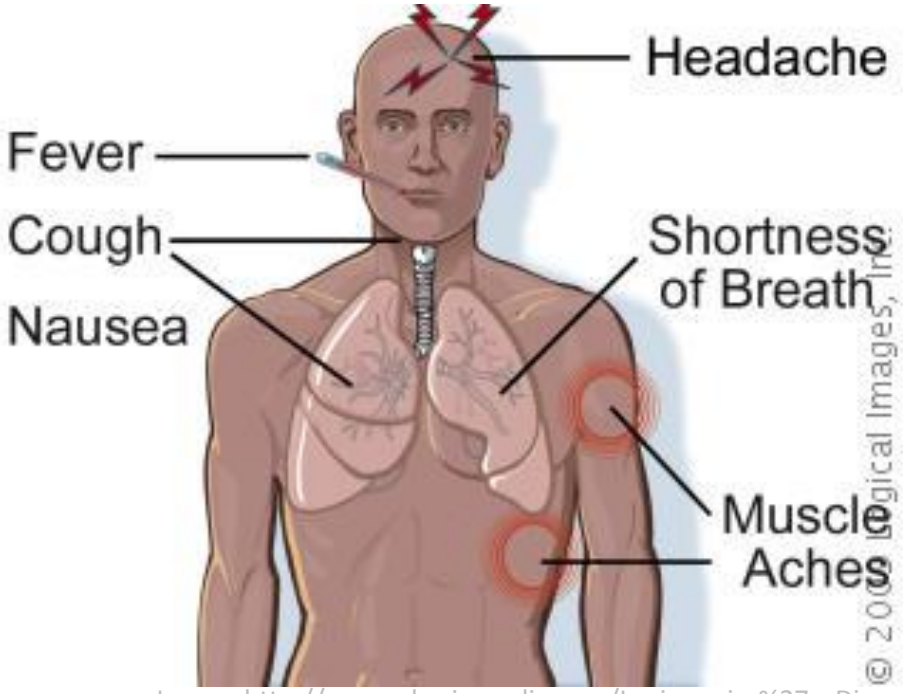


Image: http://www.physio-pedia.com/Legionnaire%27s_Disease

1. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5407a1.htm
2. Stout, J., et al. *Infect. Control Hosp. Epidemiol,* 2007.
3. Benson, R. & Fields, B. *In Seminars in respiratory infections*, 1998
4. Glick et al., Am. J. of Epidemiology, 1978

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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

December 14, 2012

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Electronic Faucets Unsafe for Use in High-Risk Patient Hospital Settings: Study Shows Automatic Faucets Carry High Levels of Bacteria

Author: SHEA
Date Published:3/31/2011 9:00:00 AM
Publication Format: HTML, PDF
Abstract:

Dallas, TX (March 31, 2011) – Researchers at The Johns Hopkins University School of Medicine have determined that electronic faucets are more likely to become contaminated with unacceptably high levels of bacteria, including *Legionella* spp., compared with traditional manually operated faucets. The study will be presented on Saturday at the annual meeting of the Society for Healthcare Epidemiology of America (SHEA).

Microbial Ecology of Residential Hot Water Heater Systems:

Role of Hot Water System Type/Design on Factors Influential to Pathogen Re-growth: Temperature, Chlorine Residual, Hydrogen Evolution and Sediment

Randi Brazeau, Amy Pruden and Marc Edwards

October 4, 2013

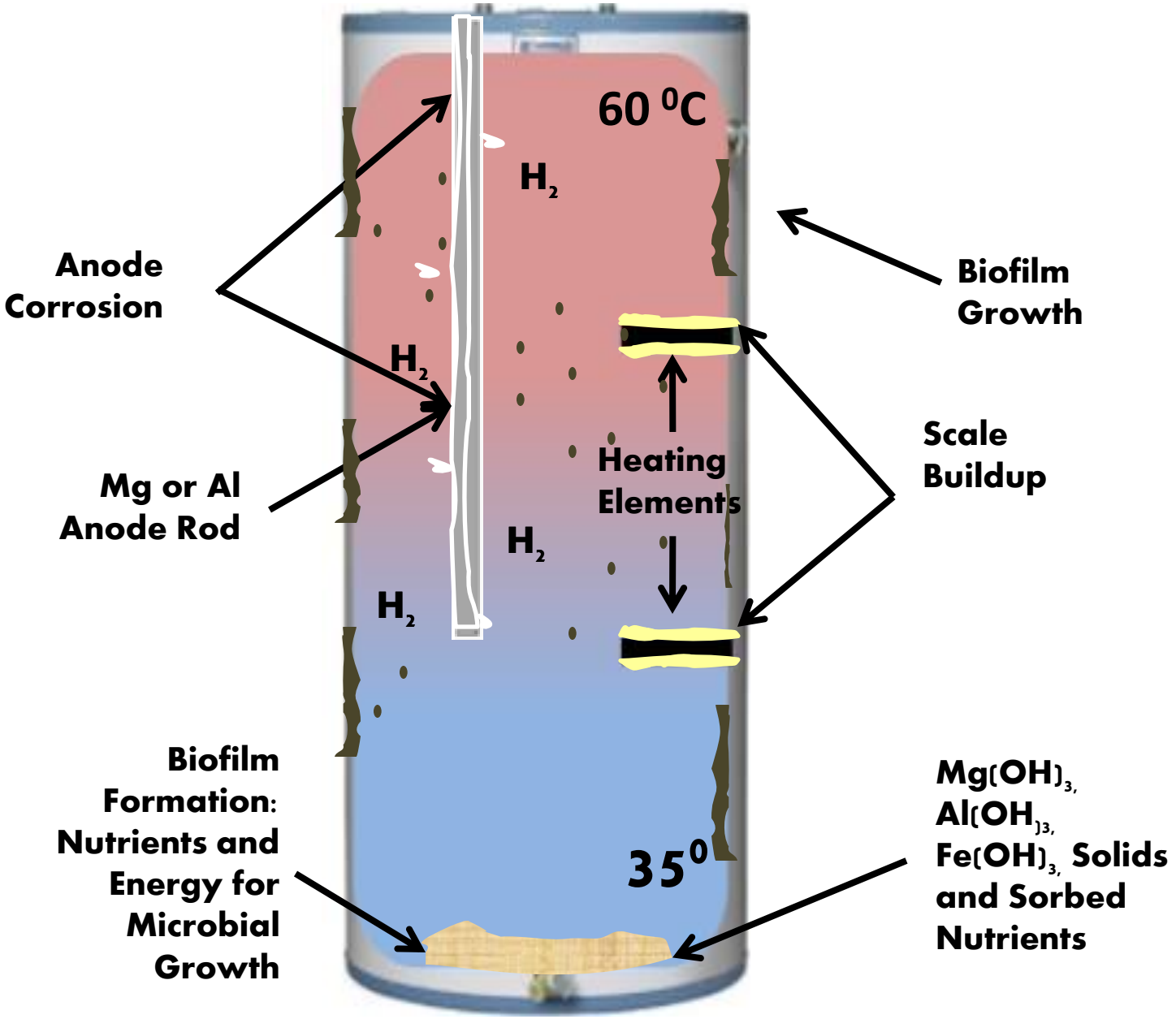
Background

- Conventional Wisdom: Temperature is the Key
  - WHO vs. US temperature setting
  - 48 °C → typically closer to 42-45 °C

Pathogen Growth → Water Heater Type

- Stratification in Electric Water Heaters vs. Gas (Lacroix, 1999)
- Pinellas County and CDC: Legionella incidence higher in buildings with hot water recirculation (Moore, et al., 2006)

Electric Water Heater



AOC (food) Generation Mechanisms

Four Potential Mechanisms

1. Nitrification (Zhang et al. 2009)
2. H_2 oxidation (Morton et al. 2005)
3. Sorption to Iron/Aluminum Sediments (Butterfield et al. 2002)
4. Organics leaching from pipe materials (PEX)

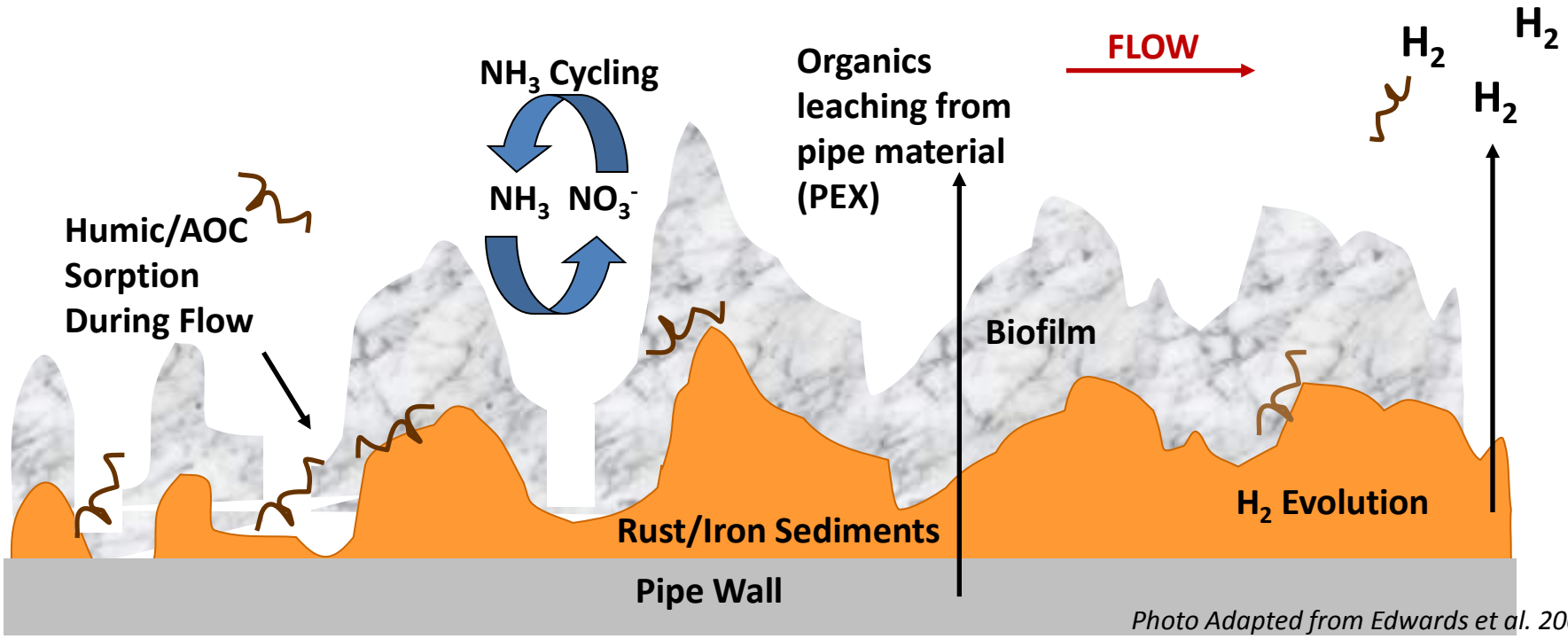


Photo Adapted from Edwards et al. 2006

AOC Generation Mechanisms

- **H_2 oxidizing bacteria**
  - Sacrificial anode (Al or Mg) corrodes producing H_2 gas
  - Supports growth of hydrogen oxidizing bacteria
  - Typical Mg-anode: 44” long by 0.7” wide, 490g, 5 yr lifetime

- **160 µg C/L everyday**

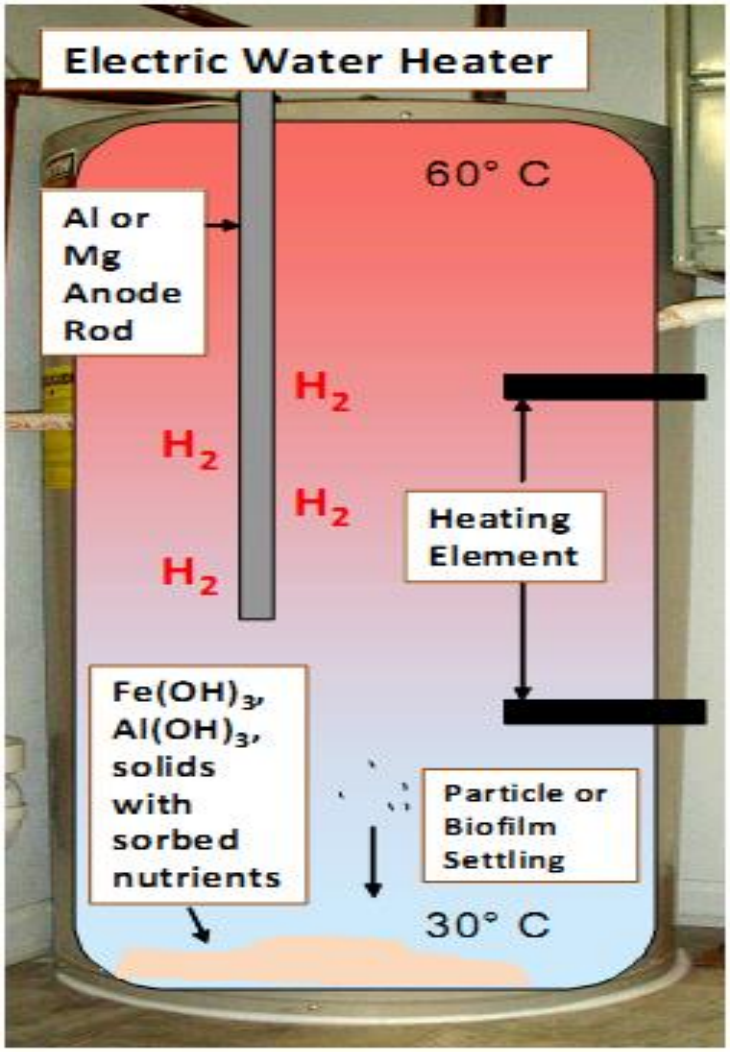


Photo Adapted from Edwards et al. 2006

Conclusions

- Temperature is important, but it is more complicated than deciding on a set point
- Recirculating systems have more H_2, less chlorine, less oxygen, higher turbidity and higher metals than standard systems
- Design and operation of hot water systems is important for comfort and health
- Organic matter (food) can be generated in hot water systems

Highlights of:

- Unleaded Brass Performance Research
- Hex Chrome Cr(VI) Issue
- LEED (Building Water Quality)
- Legionella
- Changes in Water Chemistry

Anticipating Challenges Associated with In-Building Disinfection for Control of Opportunistic Pathogens in Premise Plumbing

William Rhoads

Amy Pruden

Marc A. Edwards

Department of Civil and Environmental Engineering
Virginia Tech
Blacksburg, VA 24061

A shifting paradigm

- Responsibility for control of opportunistic pathogens is unclear
- Proposed ASHRAE Standard 188 for *Legionella*
- In-building disinfection techniques
  - Thermal/Chemical disinfection

Proposed ASHRAE Standard 188

- First legal requirement for *Legionella* outbreaks
  - Defines responsibilities of stakeholders
  - Requires certain buildings to prepare for an outbreak before one occurs
- Imperfect
  - Encourages in-building disinfection methods
  - Identifies risk factors instead of monitoring

ASHRAE Recommendations

(ASHRAE Guideline 12-2000)

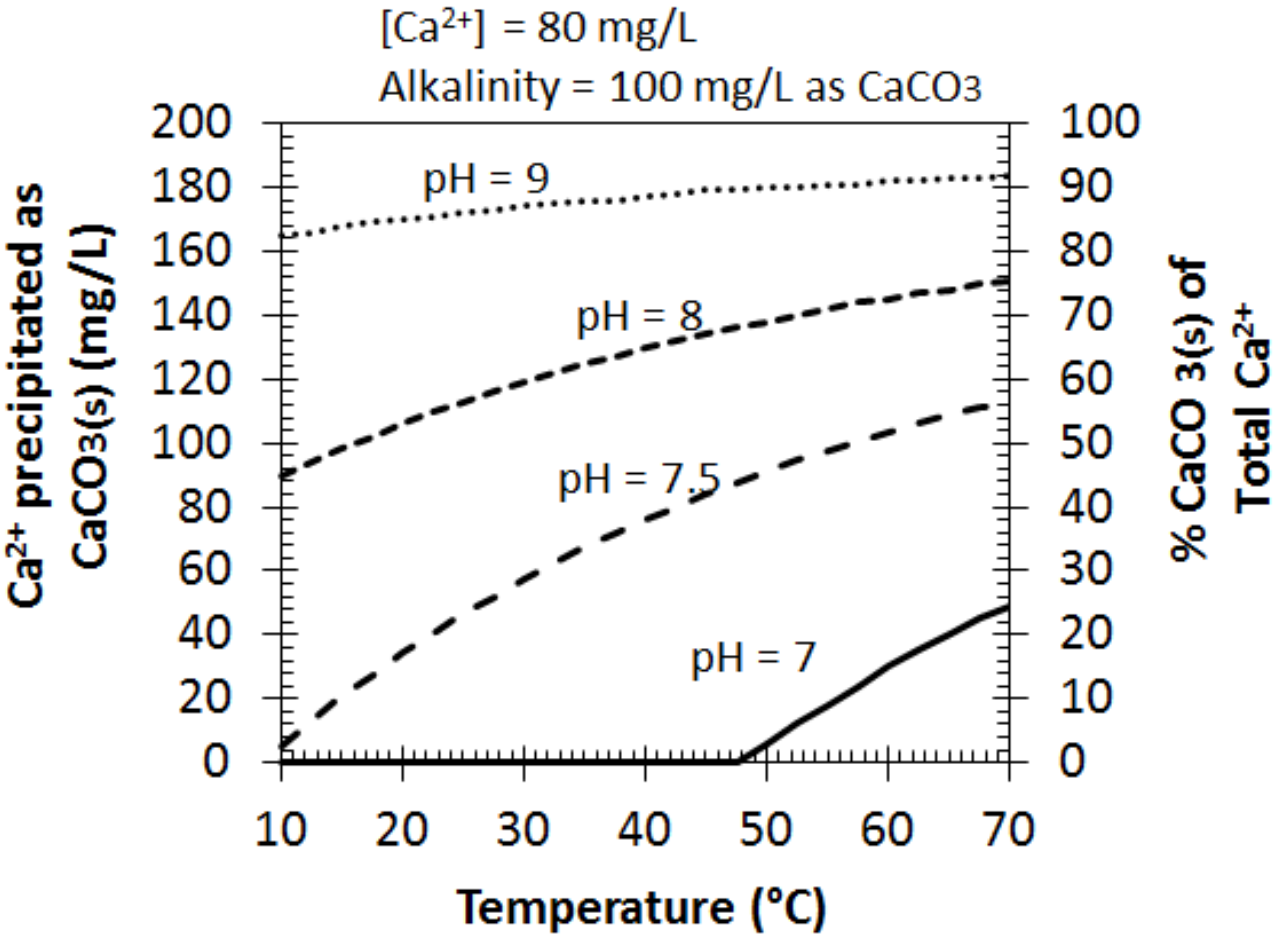
- Thermal disinfection
  - 60°C in HWH tanks
  - 51°C throughout entire hot water system
  - < 25°C in cold water systems
- Chemical Disinfection
  - Chlorine
  - Chloramine
  - Chlorine dioxide
  - Copper-silver ionization
  - UV irradiation
  - Ozone

Thermal disinfection

- EPA: 48°C in HWH tanks
- Easy to apply, but expensive
- ASHRAE: 51°C throughout entire system can't be maintained
- Abiotically increase corrosion rates?
  - Pinhole, erosion corrosion?
- Scaling
  - Precipitation of $CaCO_3$

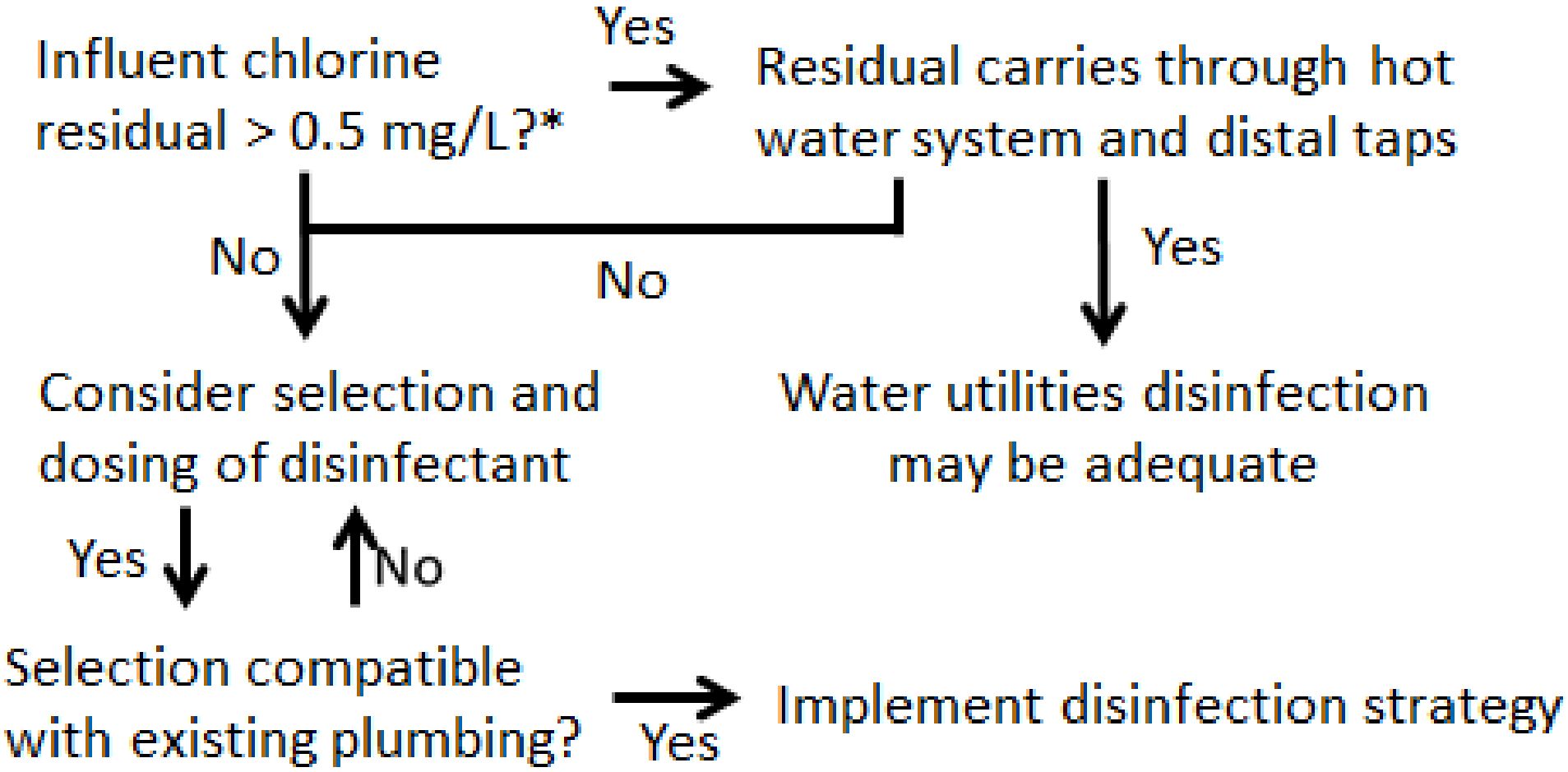
www.clean-pool-and-spa.com

Higher Temps = More Hard Water Scaling



*Decreased solubility with increasing temperature

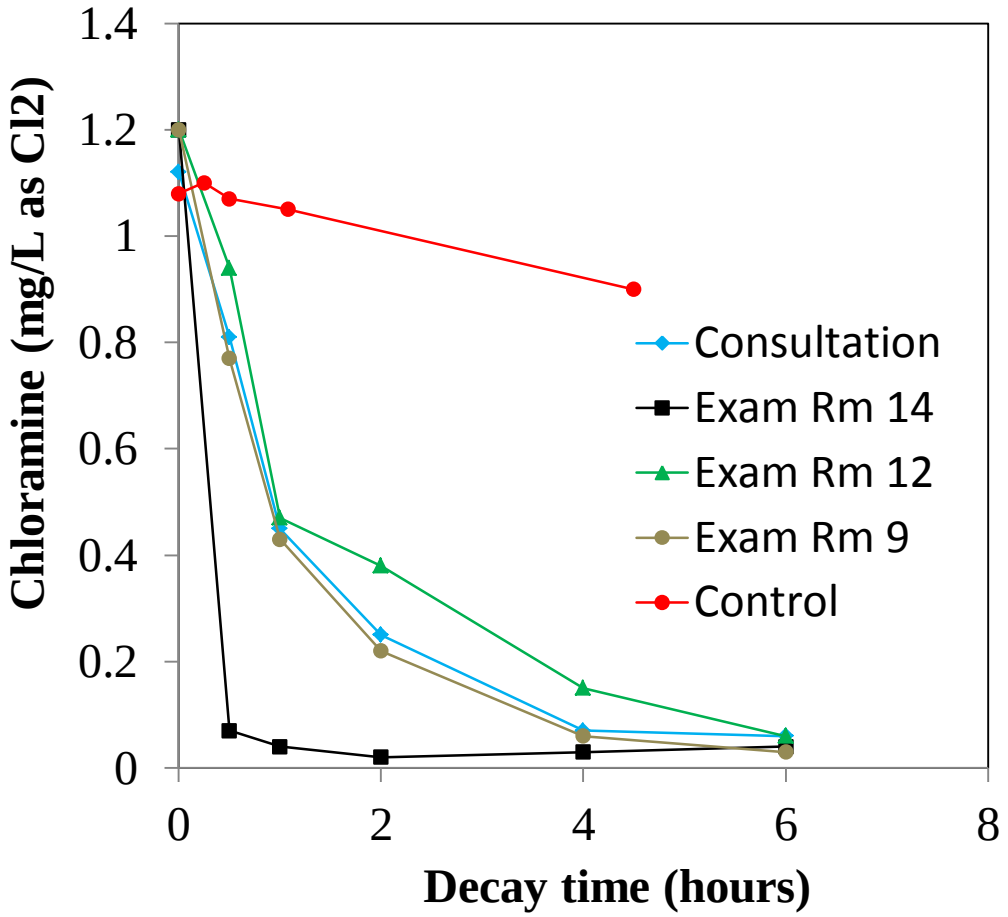
** Increase energy demand – e.g. 30% (Isaacs and Stockton, 1981)


Influent chlorine residual > 0.5 mg/L?*
Yes
Residual carries through hot water system and distal taps
No
No
Yes
Consider selection and dosing of disinfectant
Water utilities disinfection may be adequate
Yes
No
Selection compatible with existing plumbing?
Yes
Implement disinfection strategy

Chlorine and Chloramine

- Over 100 years of experience

- Stability of NH_2Cl lost in PP
- Rapid reactions with:
  - New Cu pipes
  - Nitrification



Chlorine Dioxide

- Commercial kits available provide ease of use
- USEPA MRDL 0.8 mg/L ClO_2
  - Chlorite formation
- Field studies:
  - Legionella eliminated after 1 month[1]
  - 17 month study observed high efficacy in Legionella[3]
  - Effective for dead ends[2]
  - Less effective with high temps, TOC, iron and corrosion scale[4,5]

1. Sidari et al., 2004, 2. Thomas et al., 2004, 3. Srinvasan et al., 2008, 4. Zhang et al., 2006, 5. Zhang et al., 2008

Copper-Silver

- Requires expertise, monitoring[5]
  - Discoloration of water or plumbing devices[3,4]
  - Deposition corrosion[6,7,8]
- Conflict with Cu levels in sewage[1,2]
- Field studies[9,10,11]
- Effects of pH, alkalinity, phosphates???

1. Cachafeiro et al., 2007, 2. Boulay and Edwards, 2000, 3. Stout et al., 2003, 4. Jacobs and Edwards, 2000, 5. Bartram, 2007, 6. Kentworthy, 1943, 7. Cruse, 1971, 8. Clark et al., 2011, 9. Liu et al., 1998, 10. Blanc et al., 2005, 11. Lin et al., 2002

Copper-Silver Cont'd

News Update:

<u>Effective February 1, 2013</u>

- Copper-Silver Ionization systems not allowed in European water systems
- No proof of efficacy from manufacturers

http://www.xcenta.co.uk/home/LegionellacontrolImportantinformationforusersandsuppliersofwatertreatmentsystems.html

Disinfectants in Premise Plumbing

Disinfectant/ Pipe Material	Provides Disinfectant Residual	Copper	Iron	Polyvinyl chloride (PVC, CPVC)	Polyethylene (HDPE)
Chlorine	Yes	Corrosive; rapid rxn with scale; pitting	Corrosive; rapid rxn with scale	None	Repeat shock treatments damage
Chloramine	Yes	Corrosive; rapid rxn with scale	Corrosive; rapid rxn with scale	None	??
Chlorine dioxide	Yes	Corrosive; rapid rxn with scale	Corrosive; rapid rxn with scale	??	??
Ozone	No	??	??	??	??
Copper-Silver	Yes	Ag corrosive?	Deposition corrosion on galvanized	??	??
UV	No	None likely	None likely	None likely	None likely

Conclusions

- Direct conflicts between control of OPPPs and other worthy goals such as scalding, disinfection by-products, energy conservation, water conservation and corrosion control
- Water age, disinfectant type, residual levels, and plumbing materials influence OPPP growth
  - Need for research on in-building disinfection systems

QUESTIONS? COMMENTS?

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