Water Quality Challenges: Morbidity and Mortality Associated with Building Water Systems

Occupational and Environmental Health Seminar
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Learning objectives for the seminar

- Drinking water treatment 101
- Understand *Legionella* and other OPPPs and their role in increases in morbidity and mortality related to building water systems
- Understand how OPPPs can be managed in a building water system to protect public health
- Understand current research efforts underway in building water system management
- Understand gaps in stakeholder education and the role of policy to promote good building water quality practices to protect public health

RC Harris Water Treatment Plant

Built in 1930s to showcase how City gets its water (Lake Ontario). There are 3 other WTPs.

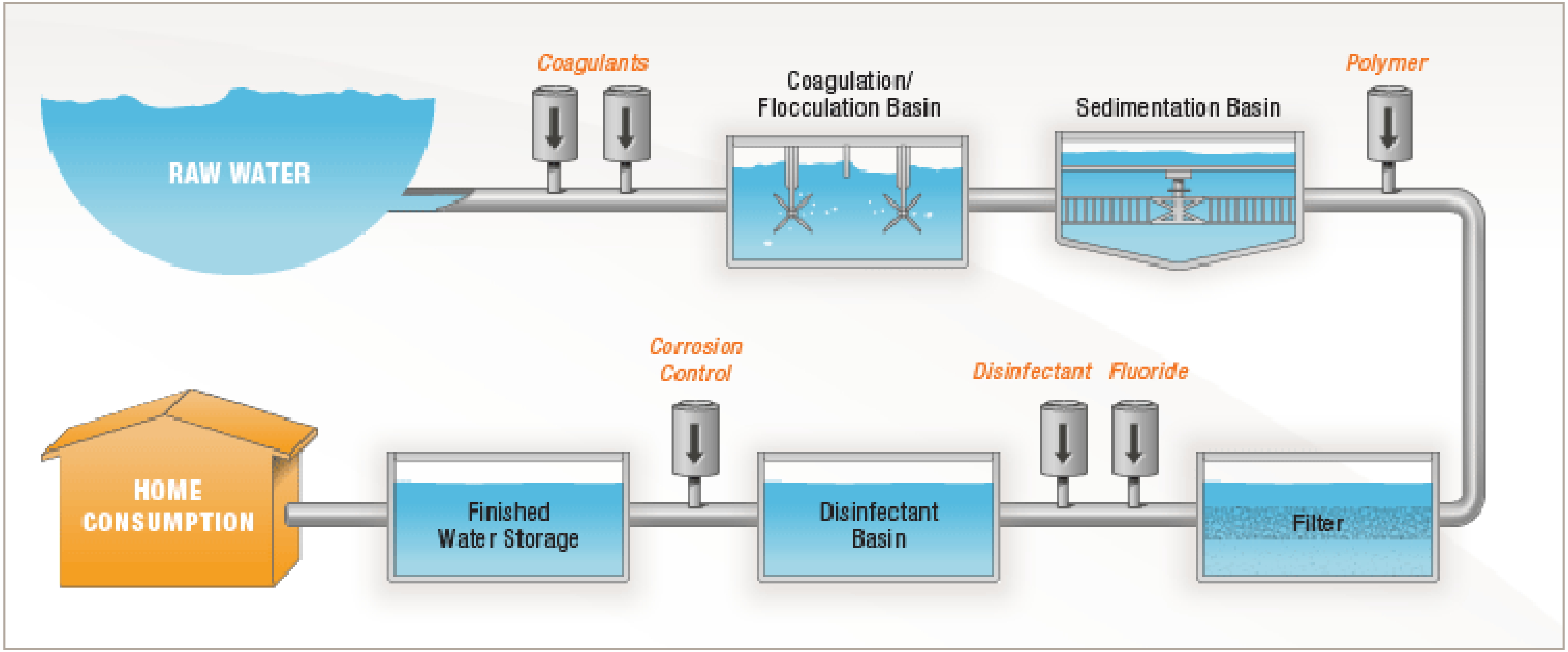
In 1992, it was named a national historic civil engineering site.

Used in dozens of films and television series as a prison, clinic, spaceship, bank….

Appeared on a stamp issued by Canada Post in 2011, in a series showcasing five notable Art Deco buildings in Canada.

950 million L/day

Surface Water Treatment Process

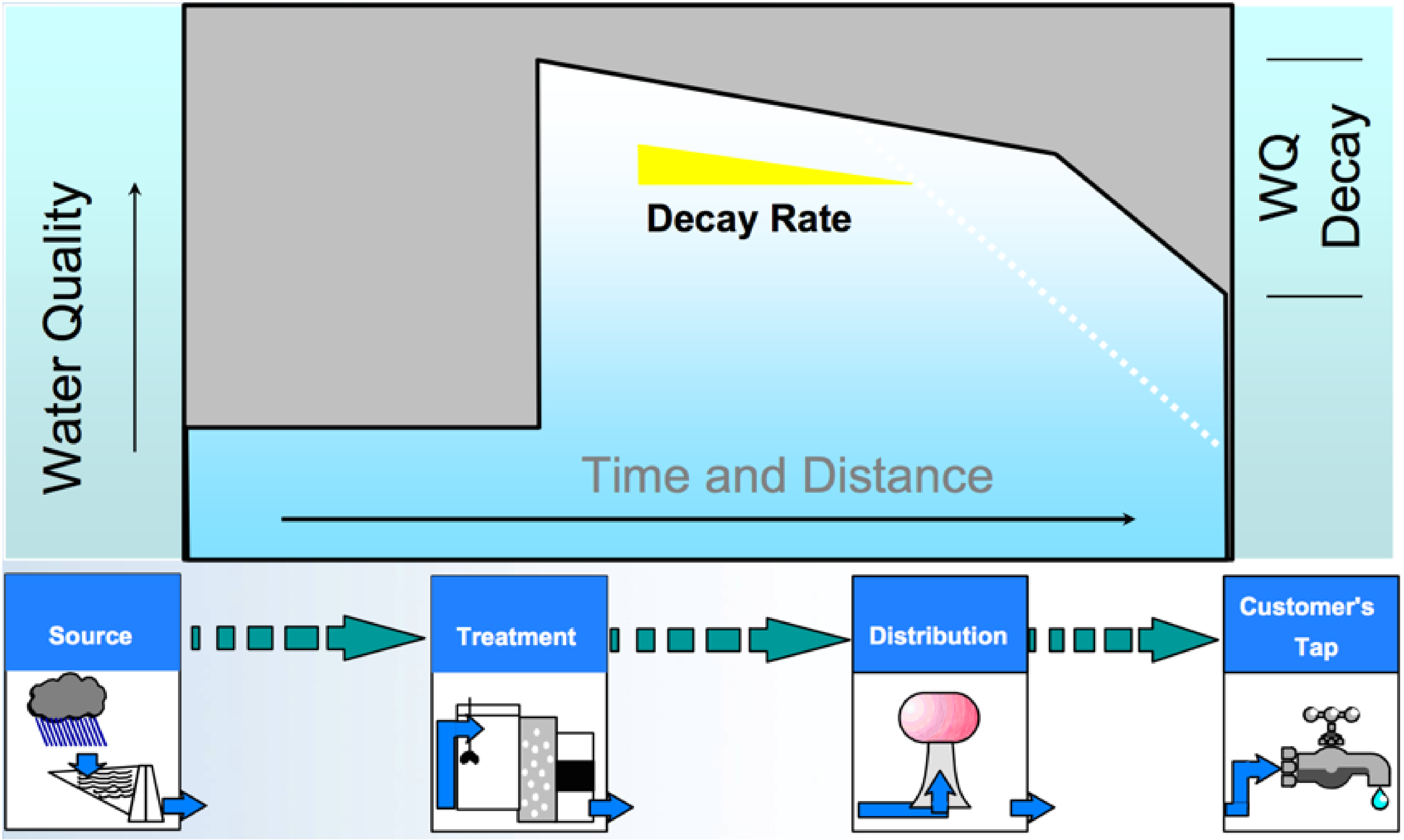


Goal of water treatment - Reduce organic material, fecal contaminants, chemical contaminants, not making water sterile

Drinking Water is Regulated

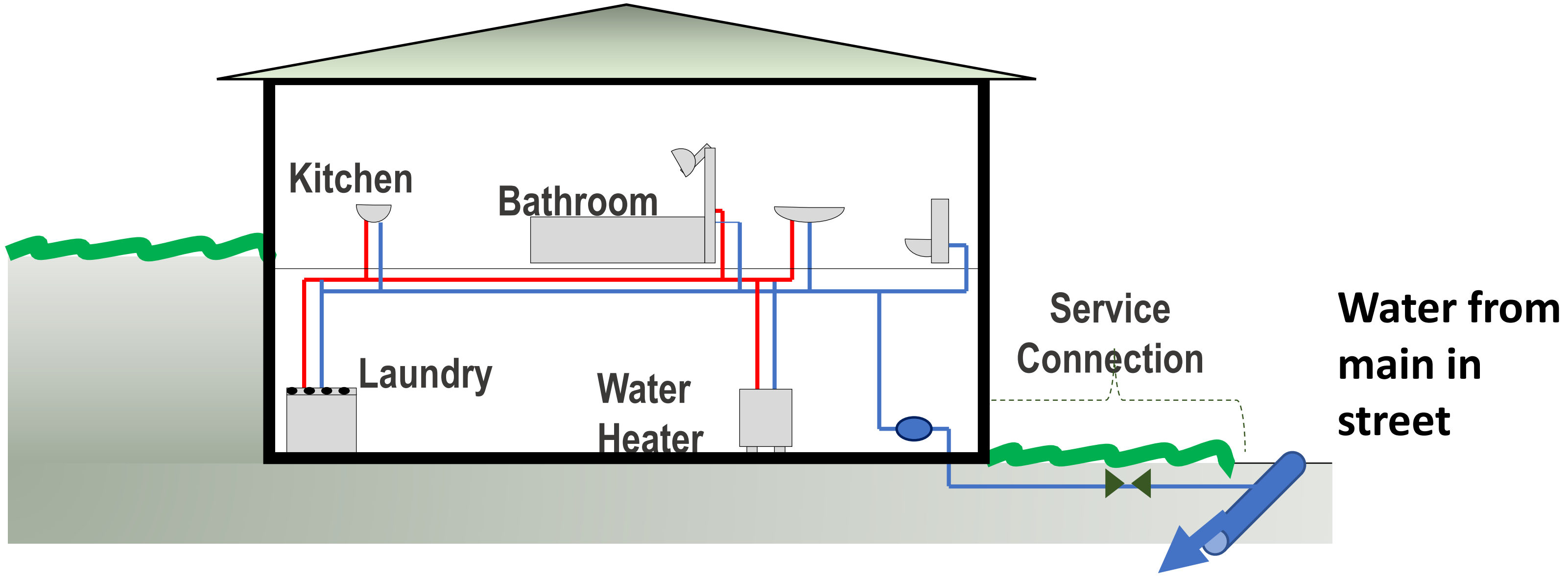
- Operational test done daily on processes (turbidity, pH, chlorine)
  - Some plants have on-line monitoring
- Samples are tested daily for microbes (coliform bacteria)
- Some chemicals are tested monthly or quarterly or annually
  - Metals
  - VOCs
  - SOCs
  - Radionuclides
  - Waterborne pathogens – *Giardia, Cryptosporidium*, enteric viruses
- All data are reported to the regulatory agency and reviewed for compliance with legal standards

Water Quality Deterioration in Distribution Systems and Buildings



Premise (Building) Plumbing

- Water supplier is no longer legally responsible for WQ in the pipes
  - exception in US and Canada is the Lead and Copper Rule.
- WQ responsibility becomes that of the building owner – individual, business, property manager.



Issues that make building plumbing unique – and can lead to WQ problems

- High SA to V ratio
- Materials
- Water age (LEED)
- Extreme temperatures
- Low to no disinfectant residual

- Bacterial regrowth
- High variable velocities
- Proximity to service lines
- Cross connections
- Aerosol exposure

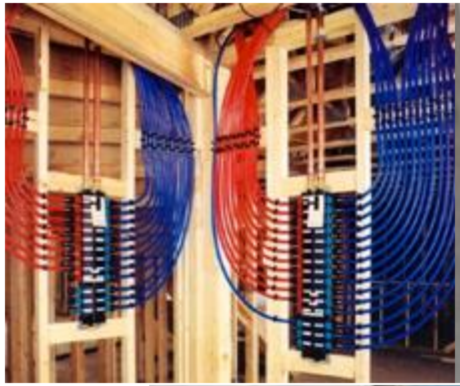
NATIONAL ACADEMY OF SCIENCES

Report, 2006

Premise Plumbing Challenges: Different Materials

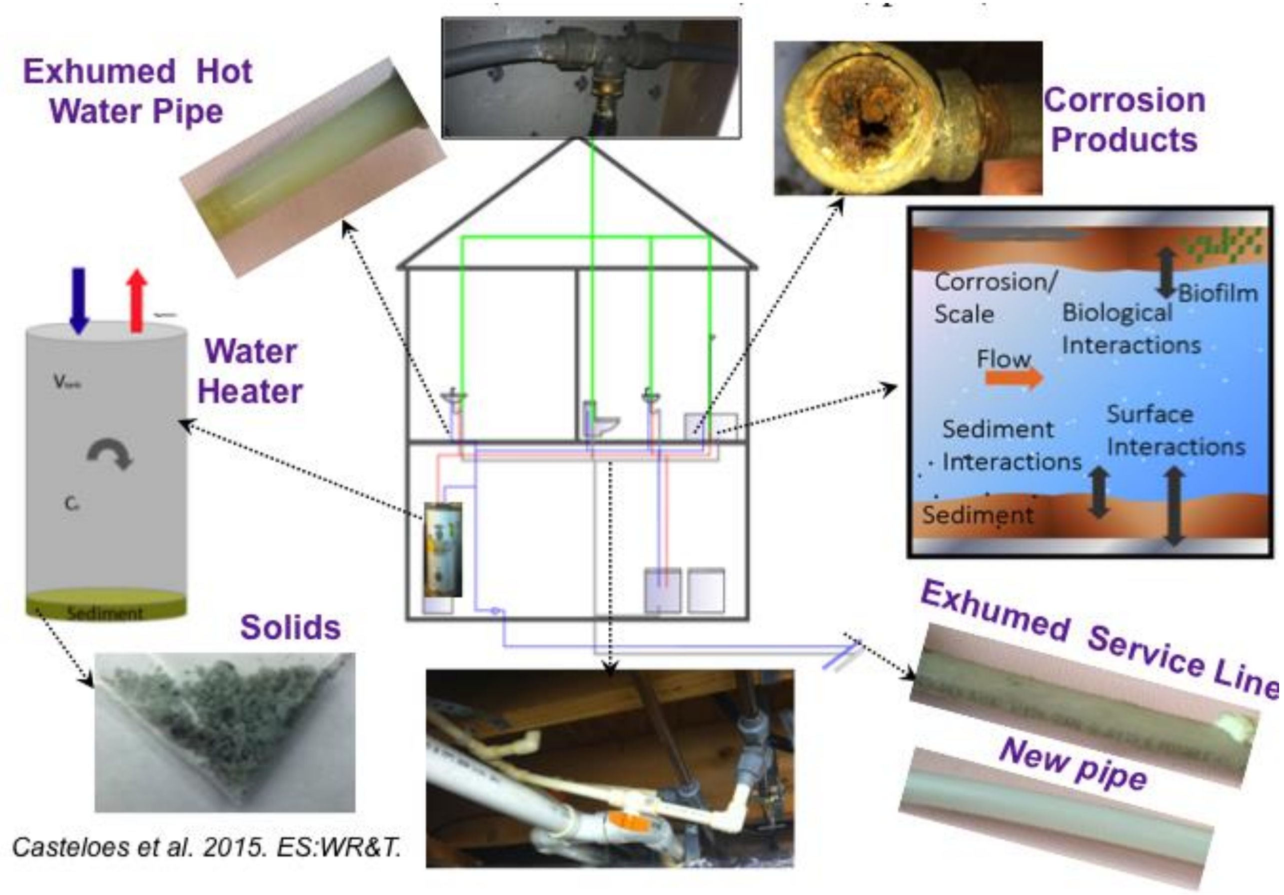
Main Materials

Premise Plumbing Materials



Building Water Systems are Diverse Components and Seldom Designed with Water Quality in Mind

- Very low awareness that BWS choices have water quality impacts
- Insufficient data on the impacts of the wide array of materials and components on water quality
- In a water distribution system, every building is a dead end



Casteloes et al. 2015. ES:WR&T.

Premise Plumbing Challenges: Unit Processes in Premise Plumbing

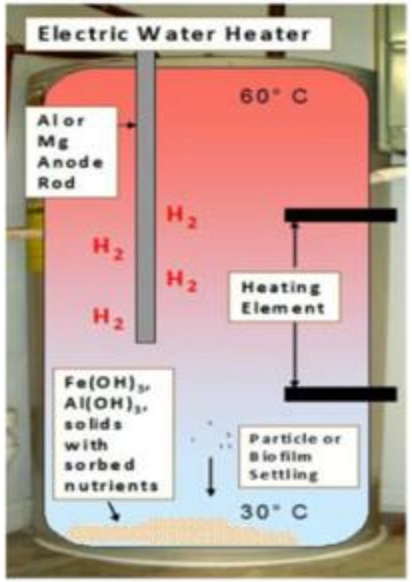


Photo from Pruden et al. (2013)

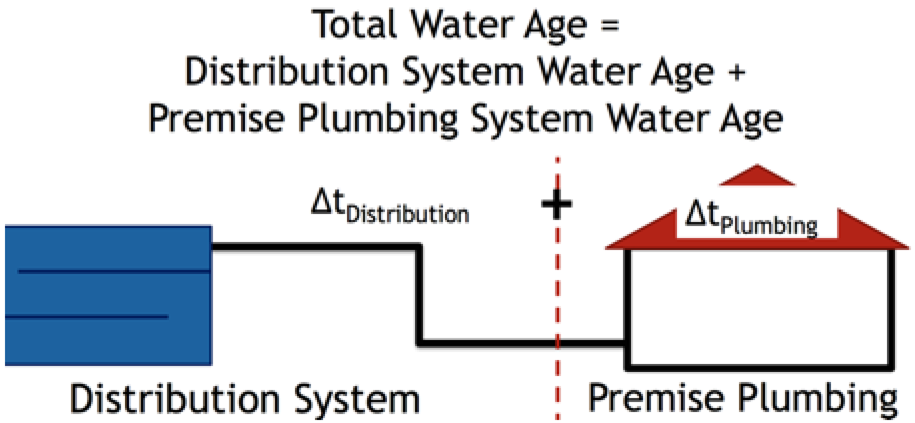
<u>Water heaters:</u>

- Extreme temperatures cause rapid disinfectant decay
- Can create ideal conditions for pathogen growth

<u>GAC Filters:</u>

- Remove chemical contaminants but also removes disinfectant

Premise Plumbing Challenges: High Water Age



Rhoads et al, 2015

<u>Every building is a dead end:</u>

Disinfectant decays

Nitrification and regrowth increases

DBP formation

<u>Water age issues likely to increase:</u>

- More green buildings (water age orders of magnitude higher)
- Installing of low flow fixtures
- Changing consumer behavior

Drinking Water 101 is completed

On to disease and death caused by buildings

Emerging Drinking Water Pathogens – e.g., *Legionella*

- Also called OPPPs (opportunistic premise plumbing pathogens)
- Different from typical pathogens of concern in DW
- **Not fecal in origin**, do not correlate with occurrence of total coliforms/*E. coli*
- Occur naturally in the water/soil environment
- Do not rely on human or animal host to reproduce
- Can survive DW treatment and multiply in DW DS biofilms
- Not monitored except perhaps in retrospective outbreak/case investigations
- Well adapted for survival in the built environment (building plumbing)

Opportunistic Premise Plumbing Pathogens (OPPPs)

The Major Players

- *Legionella* spp. (*L. pneumophila* #1)
- Nontuberculous mycobacteria (NTM)
- *Pseudomonas aeruginosa*
- Free-living amoebae (FLA)
- Thermophilic amoebae (e.g., *Naegleria fowleri*, the brain-eating amoeba)
- Others, many are Gram negative soil bacteria

Legionella

- “Discovered” in 1976 at PA hotel outbreak
- Common in the environment, found in treated DW
- Becomes established in premise (building) plumbing biofilms and is difficult to eradicate
- Colonizes pipes, tanks, faucets, showerheads, etc.
- Outbreaks and cases linked to all types of water features (cooling towers, pools, spas, showers, hot tubs, AC, ice makers, potting soils, windshield washer)

Legionella Survival in Water

optimal temp range

77 - 108°F
25 - 42°C

ASHRAE 188

- To prevent growth in cold water
  - Store below 20°C (68°F)
- To prevent growth in hot water
  - Store above 60°C (140°F)
- Recirculated water
  - Circulate with minimum return temp of 51°C (124°F)

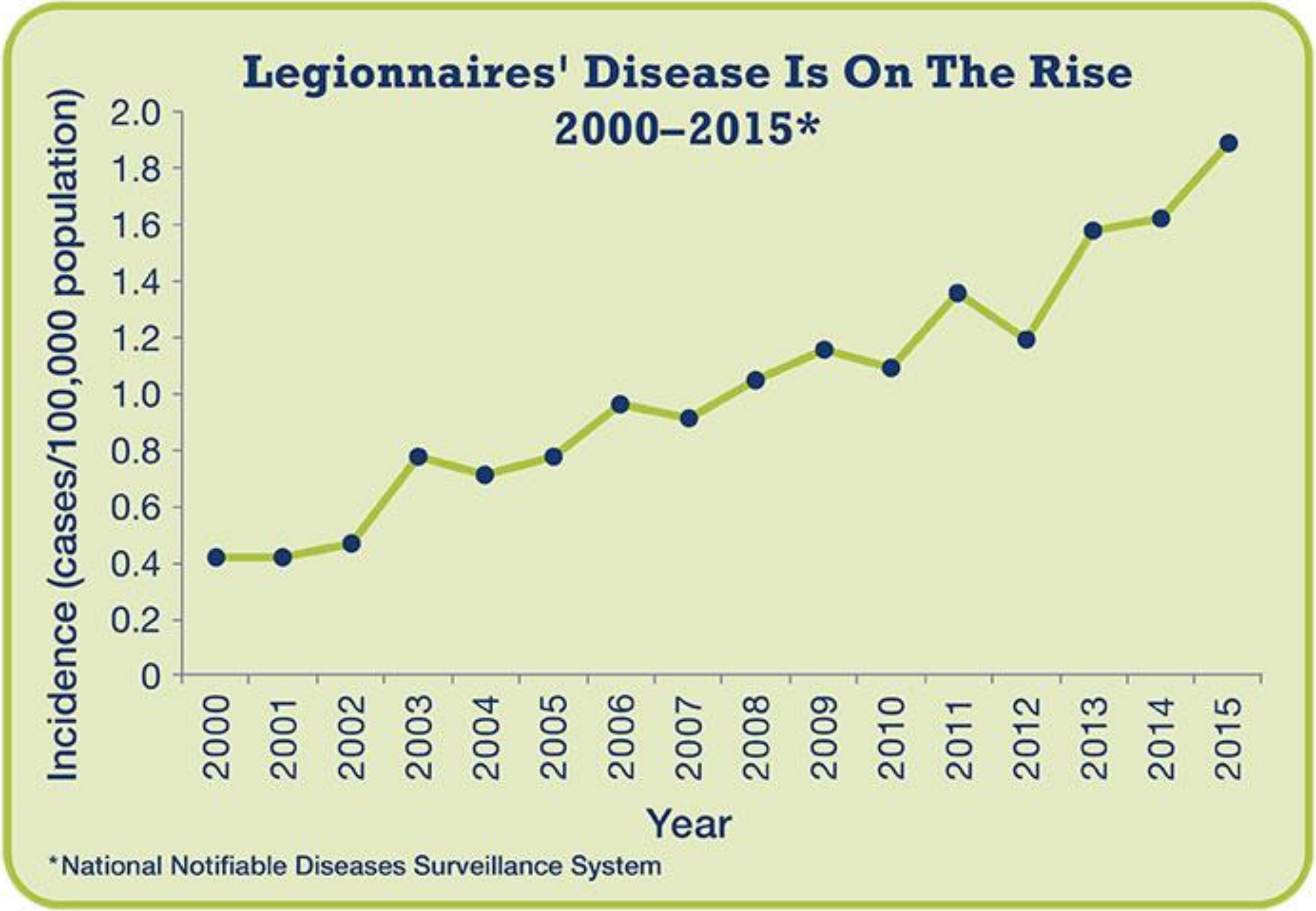
Scald Chart

Water Temperature	Exposure Time	Effects of Exposure
100° F (38°C) or below	---	2nd & 3rd degree burns on adult skin
120° F (49°C)	5 minutes	2nd & 3rd degree burns on adult skin
130° F (54°C)	30 seconds	2nd & 3rd degree burns on adult skin
140° F (60°C)	5 seconds	2nd & 3rd degree burns on adult skin
150° F (66°C)	1.5 seconds	2nd & 3rd degree burns on adult skin
160° F (71°C)	0.5 seconds	2nd & 3rd degree burns on adult skin

Legionnaires' Disease (LD)

- Pneumonia but can become systemic
- Contracted through inhalation of aerosols
- US CDC reports 8,000 to 18,000 people are hospitalized with Legionnaires' disease each year
  - Perhaps 10 X cases unrecognized
- 5 to 30% fatality rate
- $434,000,000 cost to treat in US yearly
- 425% increase over 10 years in reported cases

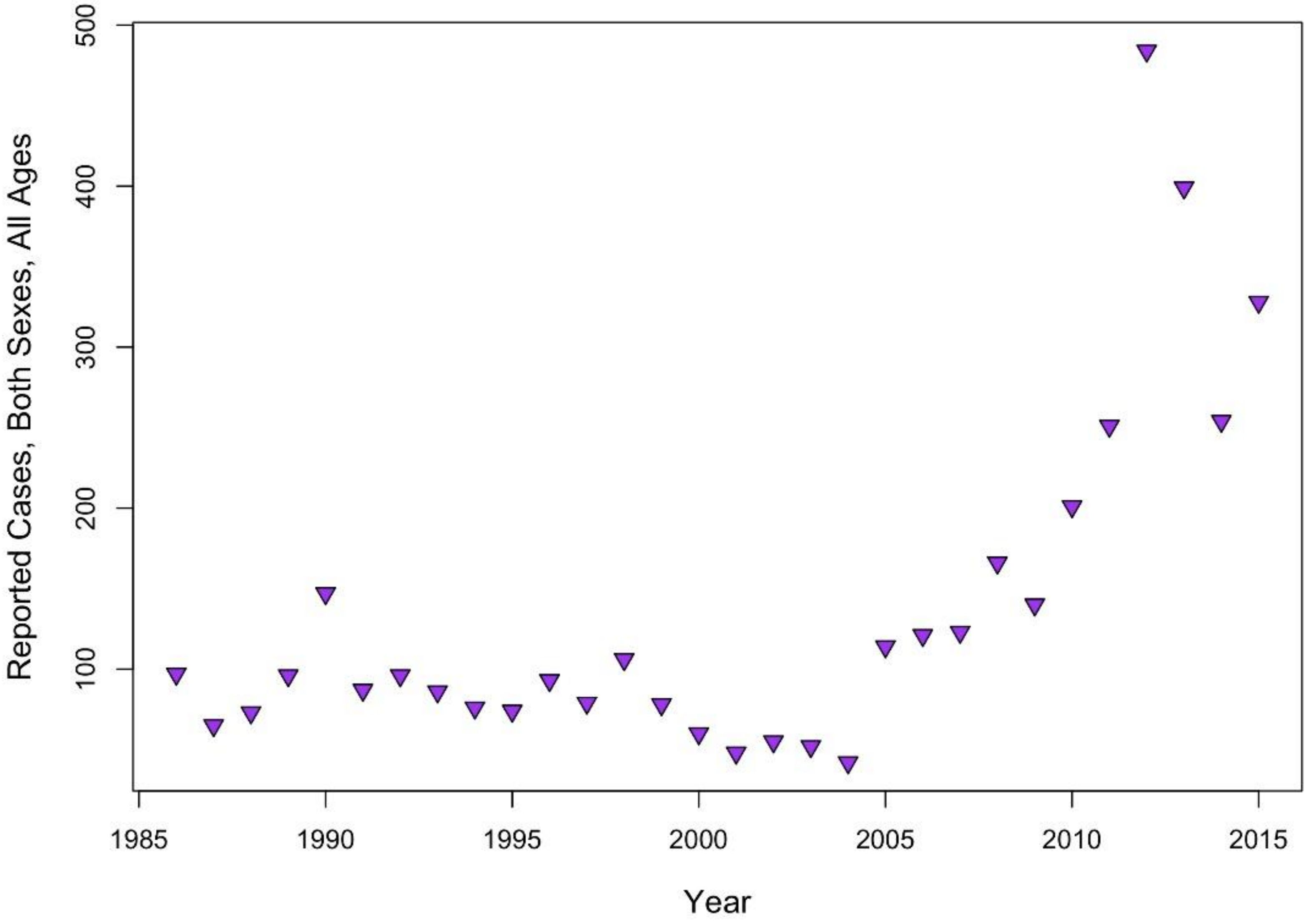
- **#1 cause of WBDOs in the US**



Legionnaires' Disease Is On The Rise
2000–2015*
Incidence (cases/100,000 population)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year
*National Notifiable Diseases Surveillance System

Reported Legionellosis in Canada

- The highest reported number of cases corresponds to roughly 1.4 cases per 100,000 people



Who is at risk?

Immunocompromised

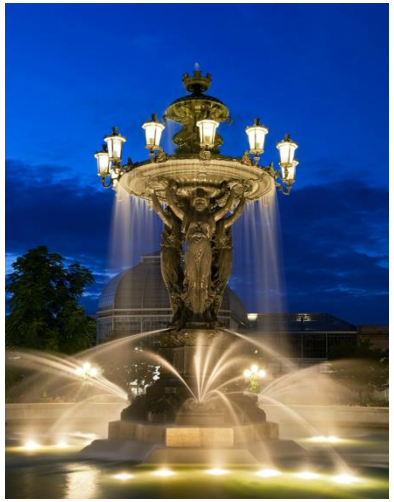
Smokers

Older adults (>50)

Babies?

About a quarter of cases have no known risk factors

Where does *Legionella* grow and spread from?



Can grow at elevated temperatures and survive and multiply in hot water heaters (25-50°C, [77-122°F])

Legionella Transmission

Inhalation

Aspiration
("Going down the wrong pipe")

"Water is safe to drink but not breathe….."
- Jen Clancy, AP Black Award Lecture, 2014

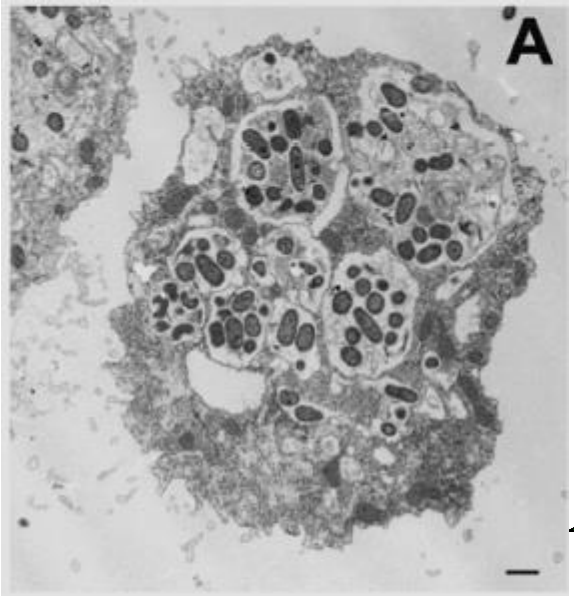
Free-living Amoebae (FLA)

- Subset of Free-living protozoa (FLP), common in natural freshwater environments
  - but also proliferate in engineered water systems, including water treatment systems, DSs, and in buildings
- Live and reproduce in the environment
  - unlike *Giardia* and *Crypto,* pathogenic protozoa but not free-living
- Ranges reported
  - <1 to 10^4 cells/L in treated water
  - <1 to 7×10^5 cells/L in DW distribution systems
  - *Acanthamoeba*, *Echinamoeba*, *Hartmannella*, *Vahlkampfia*, and *Vannella*

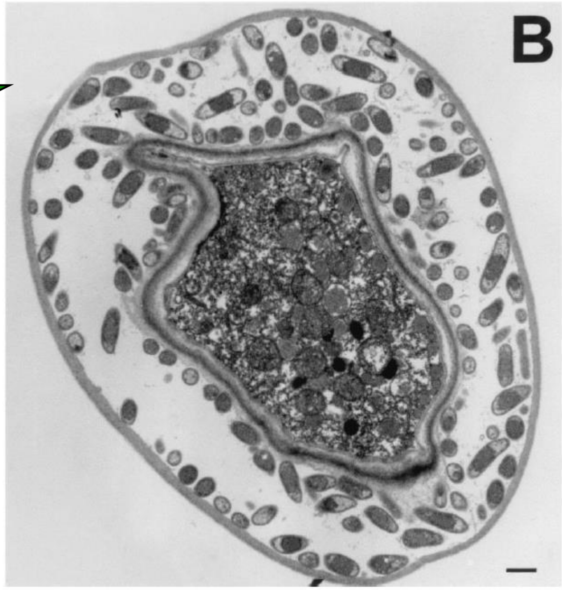
Amoeba forms showing ingested bacteria

Amplification of *Legionella* occurs in FLA

Adverse conditions



Trojan Horse



Amoebal trophozoite – bacteria in food vacuoles

Amoebal cysts highly resistant to high temperatures, biocide treatments, ...bacteria in periphery

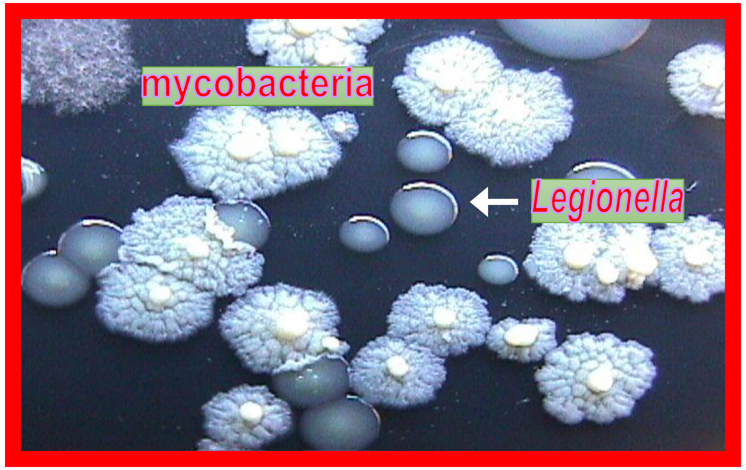
ACTIVE STAGE

RESTING STAGE

Mycobacterium species

- Most famous cause TB (*M. tuberculosis*) and leprosy (*M. leprae*)
- Group of mycobacteria common in the environment in soil and water
- Non-tuberculous mycobacteria (NTM)
- NTM infections in people difficult to diagnose & treat
  - *Mycobacterium avium intracellulare complex* or MAC (Lankenau Hospital)
  - *M. abscessus* – Greenville, SC Hospital Summer 2014
  - *M. chimera* – cardiac surgery

DW DS biofilm culture



S. Springthorpe

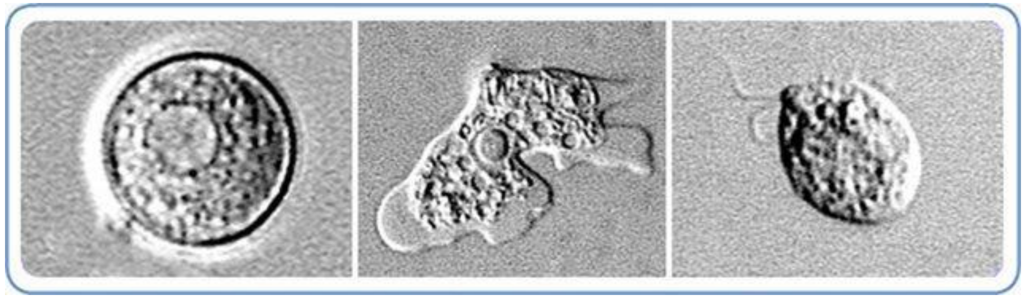
Nontuberculous Mycobacteria (NTM)

- NTM grow slowly and are resistant to a wide range of environmental temperatures (5-50°C, or 41-122°F).
- Prefer to live in biofilms attached to surfaces.
- NTM are highly resistant to the disinfectants used in water treatment.
  - Compared to *E. coli*, NTM are at least 100-fold more resistant to the disinfectants.
  - NTM include various species, so their susceptibility to disinfectants is different.
- Knowledge on NTM in water and DS biofilms is limited

Pseudomonas aeruginosa

- Common in the environment (soils, water, vegetables) and in DW biofilms
- Found in pools, spas, hot tubs, DW
- Causes skin, respiratory, UTIs, and eye infections, but also endocarditis, pneumonia
- *P. aeruginosa* is #1 pathogen isolated in US hospitals
- Many strains are antibiotic resistant
- Hospital acquired infections (HAIs)
  - In hospitals – at risk patients include those on breathing machines, with devices such as catheters, and wounds from surgery or from burns
  - Can be life threatening
  - Spread through the air, from person-to-person contact, or contaminated equipment
- Infections are not the result of ingesting DW

Naegleria fowleri - the 'Brain-eating Amoeba'



- Occurs naturally in warm fresh water
- Grows best at higher temperatures, up to 115°F or 46°C.
  - lakes, rivers, naturally hot or geothermal water such as hot springs, warm water discharged from industrial or power plants, geothermal well water and soil.
- Rare and devastating infection of the brain called primary amebic meningoencephalitis or PAM.

N. fowleri

- Usually linked to recreational water
- Contaminated water is forced into the nasal passages

Penetrates the nasal mucosa, migrates to the olfactory nerves where it enters the brain. The amoebae produce enzymes that liquefy brain tissue.

OPPPs Occurrence Review

- Found in source water
- Reduced through DW treatment (but water is not sterile)
- Begin to regrow as water moves through the supply system
- In buildings they find their niche and can multiply to high levels
  - Low or no chlorine left in the water
  - Water not moving in pipes
  - Temperatures are in optimum growth range
  - Protected in surface biofilms
  - Shed into water steam and aerosolized

Case Studies

- Hospitals in US
- None had issues with infectious diseases that led to investigation
- Investigations driven by:
    1. Discolored hot water
    2. + *Legionella*
- Conducted building assessment and recommended water management plan

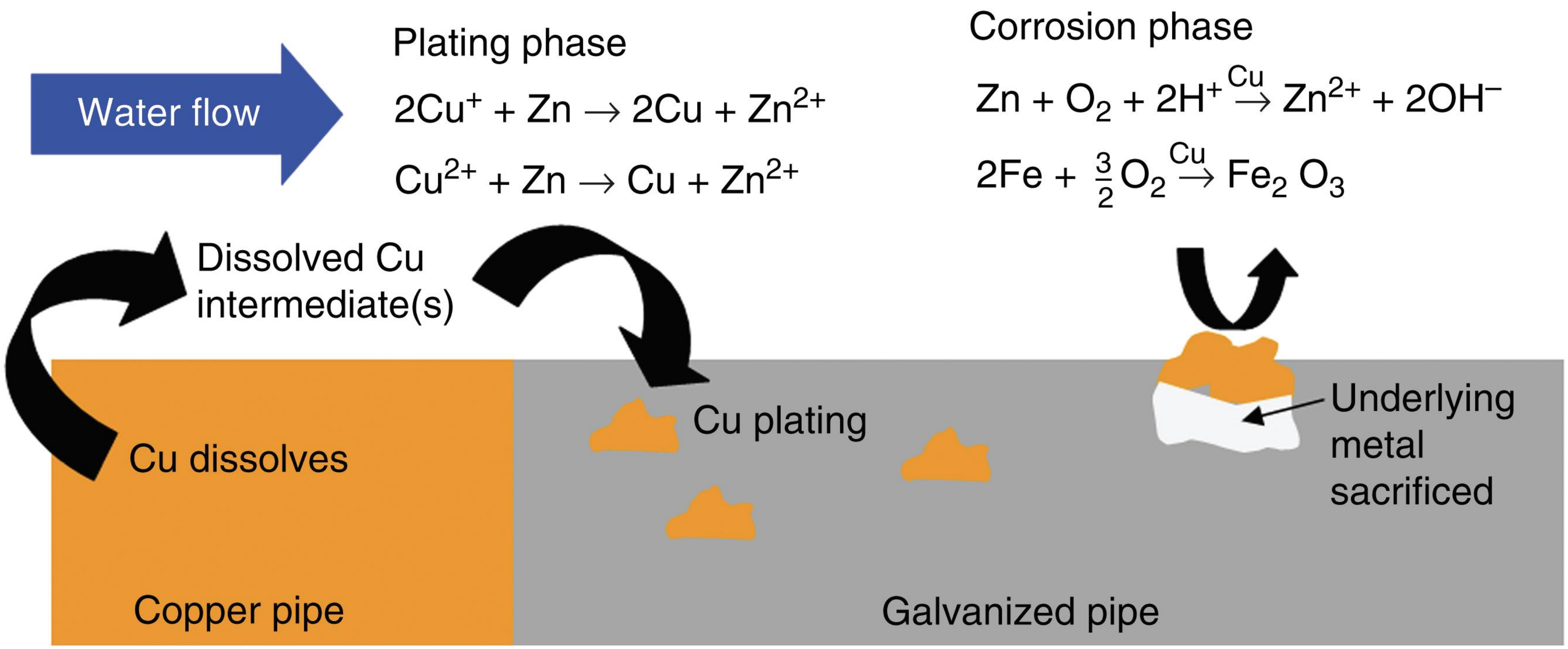
Case Study 1

- 150,000 ft^2 facility, commissioned in 2000
- Provides ambulatory services to military personnel
- In 2016, discolored water was reported in taps
- Flushing was implemented but discolored water persisted in some locations

Findings:
Discolored Water and Corrosion

- Some iron valves have been replaced due to corrosion
- No discolored water in cold water
- Discolored water in hot water due to accumulated particles
- Elevated lead in some samples

Cause of the Corrosion and Discolored Water



Clark and Edwards (2016)

Metals Results

Sample Location	Copper (µg/L) Secondary Standard = 1000	Iron (mg/L) Secondary Standard = 0.3	Lead (µg/L) Action Level = 15
POE	ND	0.51	ND
Softener In	8.9	ND	ND
Soft Out	ND	ND	ND
Hot Utility	500	0.15	2.1
1383 H	**150,000**	**72**	**1,100**
1383 H2 (post clearing)	810	**0.47**	5.3
2424 H	360	0.085	1.2
2303 H	**4600**	**3**	**39**

Other water quality findings

- Significant chlorine present at POE and cold water taps (1.2-2.0 mg/L)
- Low chlorine in hot water (max = 0.05 mg/L)
- POE turbidity was 0.3 NTU and <1 NTU in hot water taps that were visibly clear
- Discolored hot water samples had turbidities of 77 and 186 NTU
- Bacteria counts were low; and *Legionella* non-detect (at that time)
    - Very few samples: may not be representative of all locations
    - *Legionella* have been detected since

Recommendations

- Conduct flushing to eliminate accumulated particles
- Improve material compatibility (replace dissimilar metals).
  - Flush a second time to remove any dislodged particles
- Develop and implement a water management plan

Case Study 2 - US

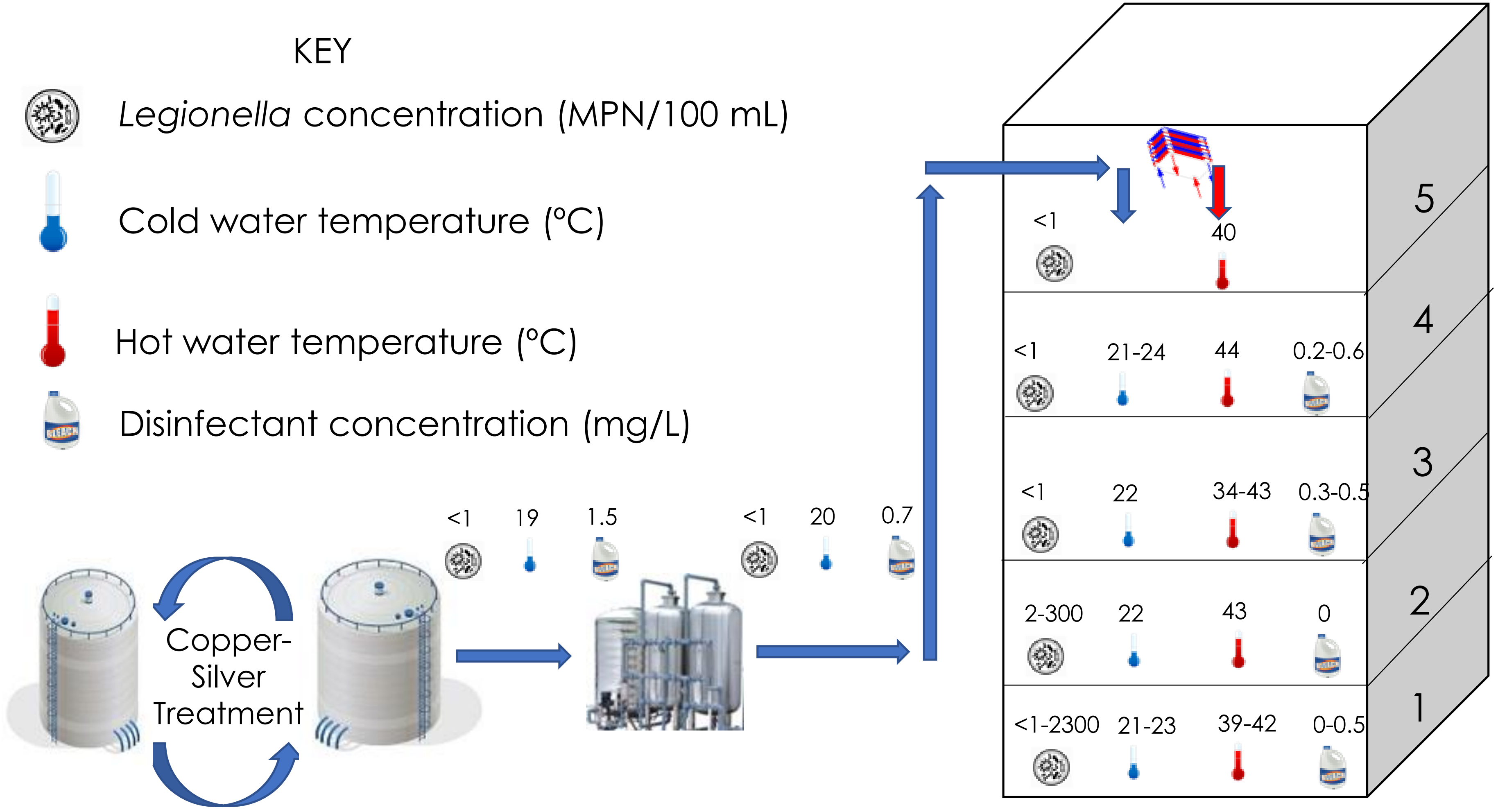
- Four story, 500,000 sq ft medical treatment facility opened on January 2014
- The 42-bed facility is a medium size, teaching hospital
- Wide range of services including surgical, emergency, dental, orthopedics, etc.
- Positive *Legionella* prior to site visit
- Driver to develop a water management plan – CMS directive

Case Study 2 - US

WMP Site Assessment:

- Reviewed facility plans and drawings prior to visit
- On site
  - System review
    - Start at source and move through the system to distal taps
    - Field testing for Cl, pH, temperature, conductivity
    - Sampling for *Legionella*, *Pseudomonas aeruginosa*, free-living amoebae, thermotolerant amoebae (e.g., *Naegleria* fowleri), NTM and HPC
  - Hazard assessment
  - Recommendations to reduce hazards (WMP)

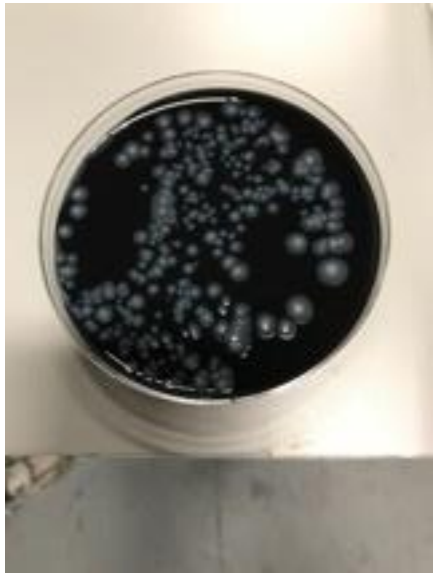
Legionella Occurrence in Hospital with Copper-Silver Treatment



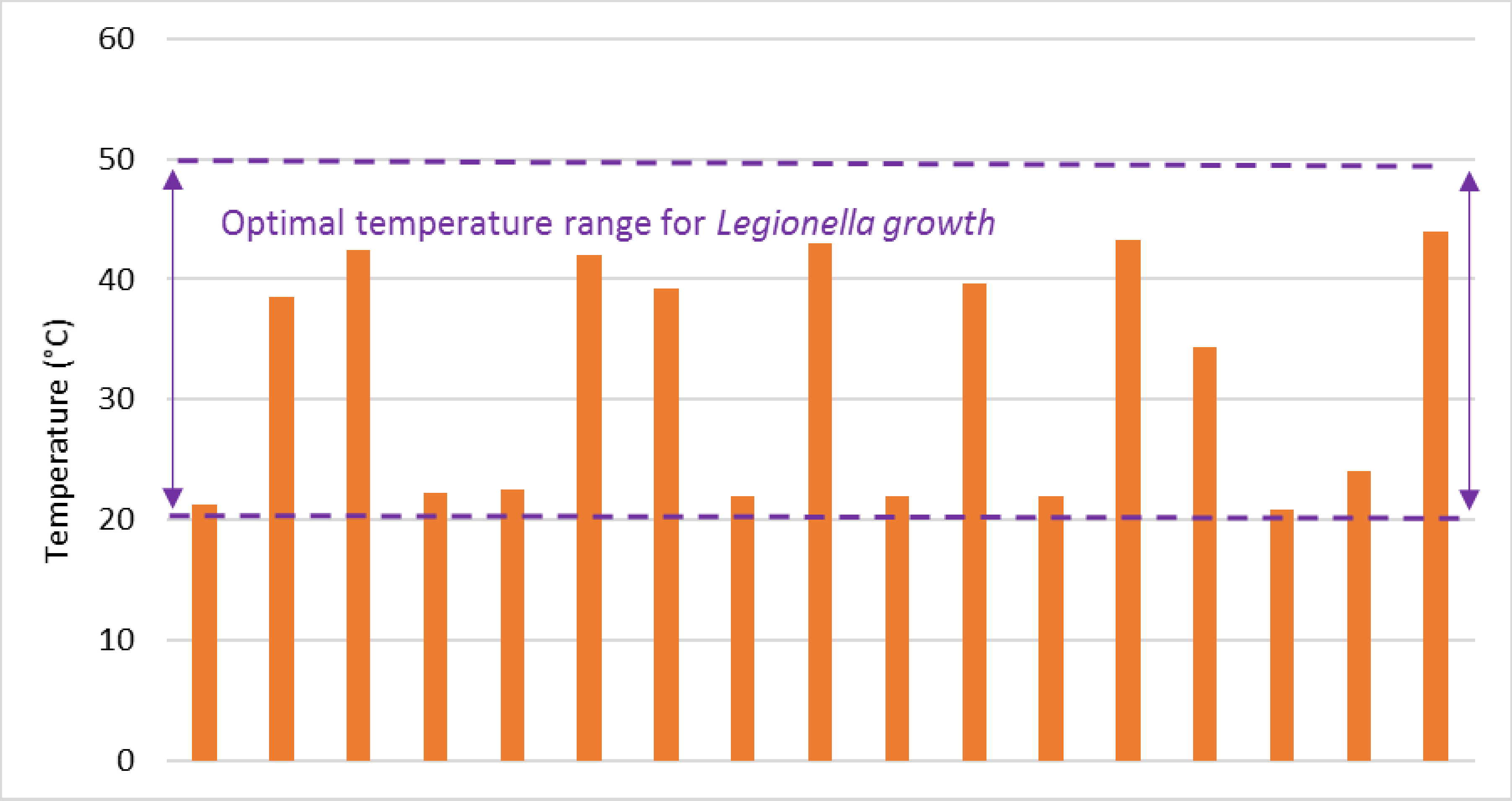
Case Study *Legionella* Occurrence in Hospital

Sample type	Total samples collected	Number positive for *L. pneumophila*	Percent positive for *L. pneumophila*
Cold water supply piping	6	0	0
Hot water supply/return piping	4	1	25
Cold sink tap POU	8	5	62
Hot sink tap POU	8	3	38
Blended hot/cold sink tap POU	1	1	100
Blended hot/cold shower tap POU	2	1	50
All point-of-use samples	19	10	**53**
All samples	**29**	**11**	**38**

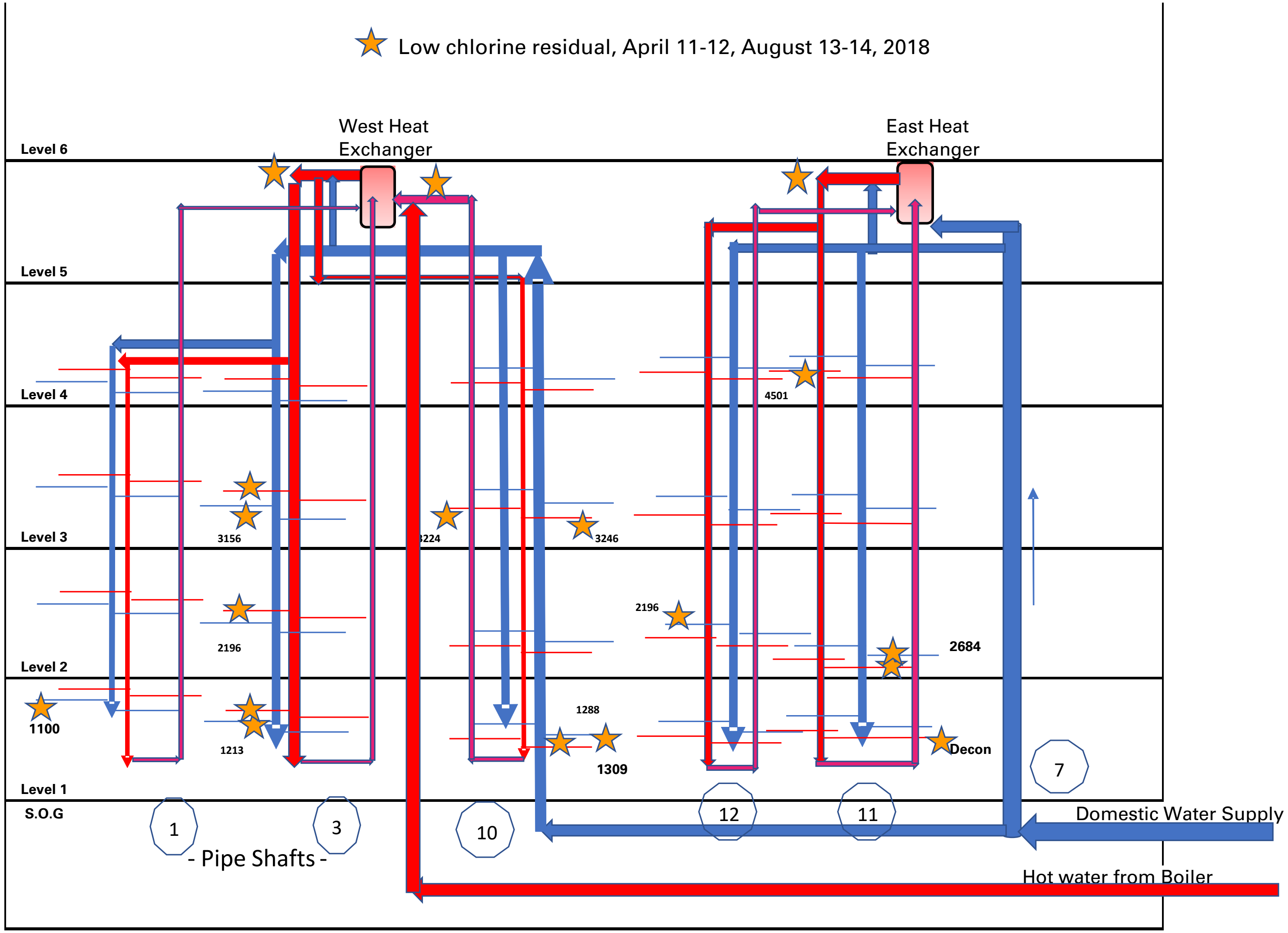
1 mL tap water, nurses station



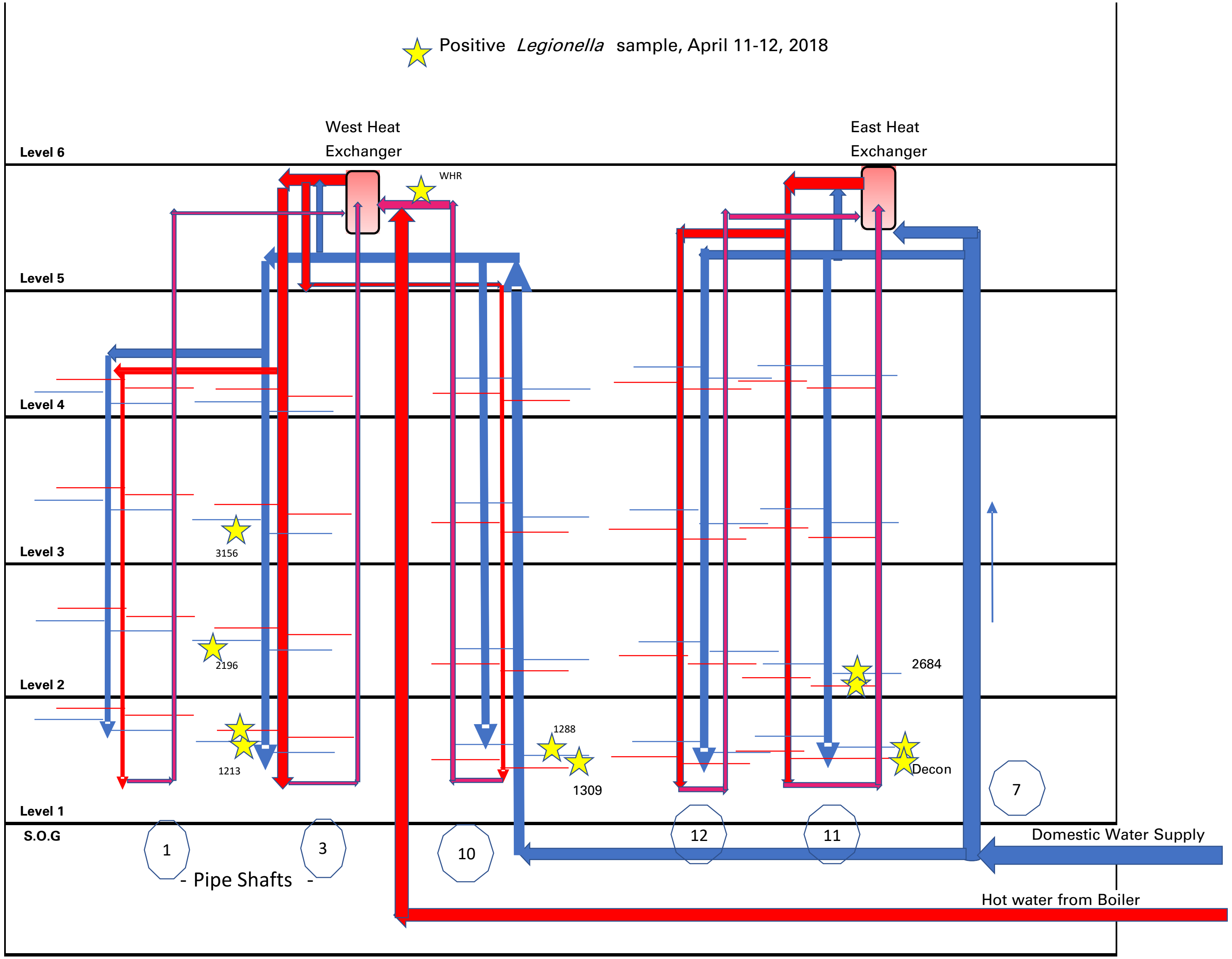
Temperatures at POU Sinks



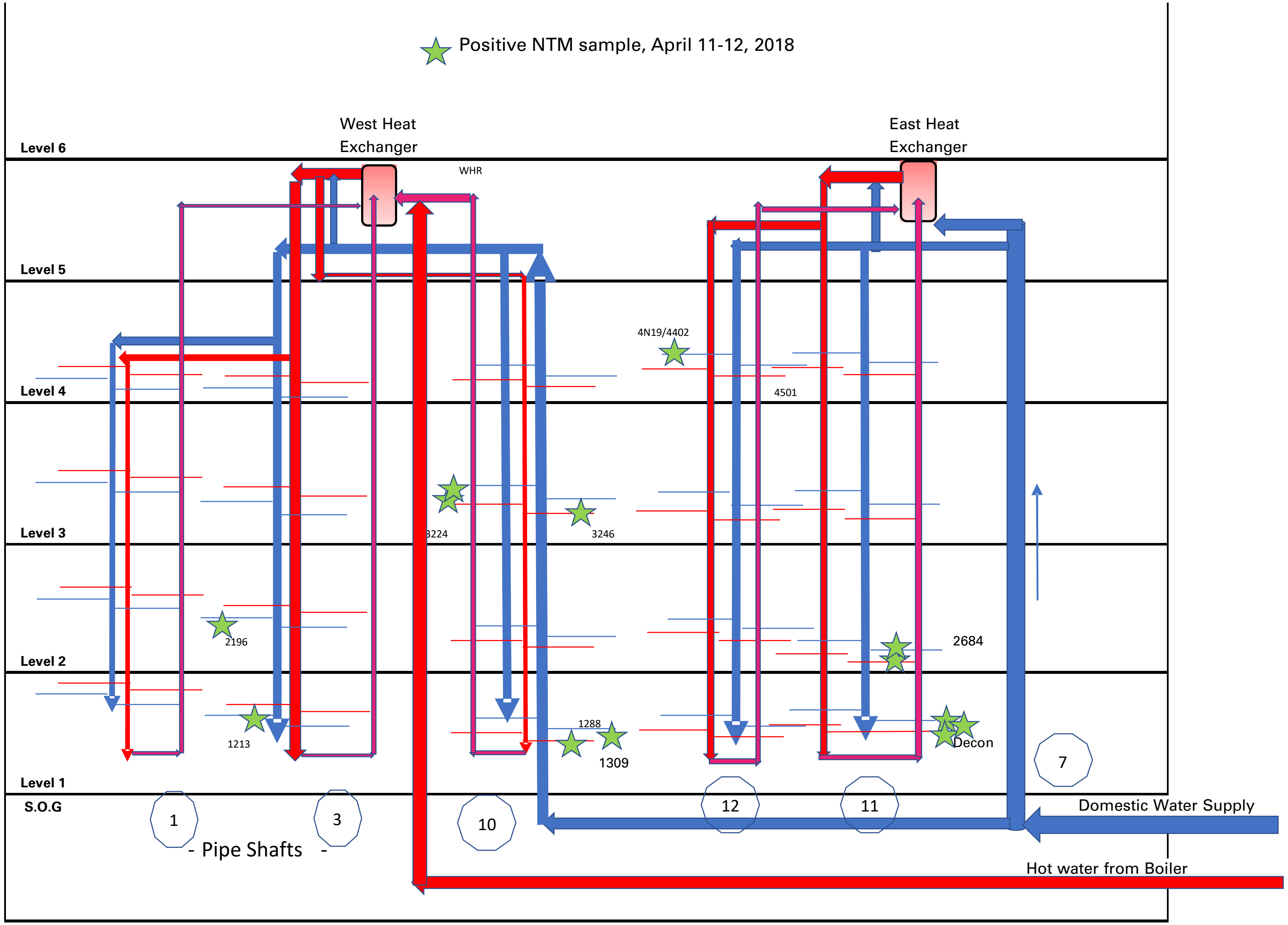
Chlorine residual decreases as water ages; lower floors have lower residuals as water enters at the top floor and flows to the bottom



Legionella positive samples increase as water ages; lower floors more contaminated as water enters at the top floor and flows to the bottom



NTM positive samples increase as water ages; lower floors more contaminated as water enters at the top floor and flows to the bottom



Case Study 2

Overall Findings:

- *Legionella* and NTM increased at distal points in the building with lower chlorine residuals and higher water age
- In most cases, when free-living amoebae (FLA) was present *Legionella* was also present
- In some cases, *Legionella* was detected even when copper and silver were present
- Water temperature at all POU taps was within the optimum *Legionella* growth range

Case Study 2

Hazards and Potential Areas of Concern – Water Management Plan

Hazard Evaluated	Potential Areas of Concern	Risk
Incoming water at Point of Entry (POE)	Variable water quality can lead to operational issues	Medium
Cold water pipes and storage tanks are not insulated	Ambient temperatures will serve to warm cold water supply to within optimal range for microbial growth	High
Cooling Towers	Monitoring program needs to be tightened and actions taken when operating parameters are out of spec	High
Ineffective copper/silver ion concentrations; inability to control *Legionella* in system	Full scale confirmation	High
Low chlorine disinfectant residual	Cold water taps with little or no disinfectant, even after extensive rinse	High
Low hot water temperatures throughout the system	Hot water temperatures at some points of use are consistently below 120°F	High

Case Study 2

Hazards and Potential Areas of Concern

Hazard Evaluated	Potential Areas of Concern	Risk
Amplification of pathogens in dead legs	Several dead legs were identified throughout the plumbing system. Microbial growth can occur in these dead legs.	High
Low use taps	Water in pipes feeding low use taps or processes will be subject to aging, residual decay, contribution of nutrients to biofilm and uptake of organisms from biofilm	High
Long pipe runs supplying Points of Use	Circuitous plumbing routes force water to travel through extensive lengths of pipe, similarly offering the opportunity for aging, residual decay, contribution of nutrients to biofilm and uptake of organisms from biofilm	High
Ineffective under sink POU filters; Inability to control *Legionella* in system or in sink faucet	Full scale confirmation	High
Intrusion from facility non-potable system	Backflow preventers are installed and checked regularly.	Low

Case Study 2

Hospital Course Of Action – the Water Management Plan

Cooling Towers:

- Monitoring
- Response plan

POE:

- Specify incoming WQ requirements
- Routine, continuous monitoring of chlorine and TDS
- Set up phone tree to notify hospital of AWTP operational changes
- Establish response plan for hospital [turn or adjust IX]
- Remove CSI

Hospital COA, WMP continued

Low use piping and POU:

- Identified
- Eliminate or modify
    - Ability to restore rapidly due to operational commitments
- Monitor
- Sanitize with temperature
- Flushing program for situations that cannot be eliminated or modified

Temperature Control

- Insulate hot and cold pipes
- Relocate tempering valves to floors, sectors
- Consider maximum temperature requirements at taps

How can we prevent Legionnaires' and other diseases?

We know how to control *Legionella* in building water systems

- Keep the cold water cold (below 20°C, 68°F) and the hot water hot (60°C, 140°F) – watch out for scalding
- Keep the water moving, avoid stagnation
- Maintain plumbing fixtures, clean hot water tanks
- Understand the building water system and how to **manage it effectively**
    - Identify hazards, monitor critical control points, verify that the metrics you've established to maintain good WQ are being met, and fix the system when problems arise
    - May require additional water treatment to maintain WQ
- Manage building water quality

Focus for Managing Building WQ

Sediment

Temperature

water **A**ge

disinfectant **R**esidual

Keep the cold water cold and the hot water hot **(T)**, keep the water moving **(A, R)** and the system clean **(S)**

Where do we go from here?

"Within the building plumbing system many factors can create an environment for microbial regrowth. Control of OPPPs is complex and requires a multifaceted approach. This necessitates a shared responsibility by multiple stakeholders, including residential, institutional, commercial/industrial customers, water utilities and high-risk customers. Each entity has a role, with an overall commitment to education, corrective actions, mitigation, and continued research"

-WRF Project 4664 Communications Report, Clancy et al, 2018.

Thoughts

- Limited guidance and coordination among stakeholders, and to date we have seen a ‘not my problem’ approach from the water utility side since their legal responsibility for water quality stops at the service meter.
- Building owners/operators have not been tuned into water quality within the building, assuming it is good quality at the point of entry and failing to understand it degrades significantly within the building.
    - Utilities could provide Care Instructions for maintaining good WQ

Thoughts

- Some States are requiring increasing in minimum disinfectant residuals in an effort to control OPPPs, failing to understand that a building is its own ecosystem and residual is rapidly depleted in most buildings before reaching distal taps.
- Studies that are underway to understand the building as an ecosystem will allow us to develop evidence-based control strategies to prevent OPPP infections in building water systems.