



Free Monthly Webinar Series

Challenges and Treatment Solutions for Small Drinking Water Systems

Hosted by EPA's Office of Research and Development (ORD) and Office of Water (OW)

Schedule & Recordings: epa.gov/water-research/small-systems-monthly-webinar-series

TODAY'S TOPIC:

Legionella Management and Treatment

January 28, 2020

A certificate for one contact hour will be provided for attending this webinar

Webinar Slides: Located under "Handouts" in the right navigation bar of your screen.

To Ask a Question: Type in the "Questions" box located in right navigation bar on your screen.

Webinar Support: Send email to webcastinfo@cadmusgroup.com

Disclaimer: The views expressed in this presentation are those of the authors and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency. Any mention of trade names or commercial products does not constitute EPA endorsement or recommendation for use.

Requirements:

1. You must be registered or be in a room with someone who is.
2. You must **attend** the live webinar **for 60 minutes**.
3. If in a room with others, the **names of people not logged in must be provided by the person who is logged in**. Type names in the “Questions” box or send names to webcastinfo@cadmusgroup.com.
4. If you did not request the credit at registration, send a request by responding to your registration confirmation email.



Note

Acceptance of certificates is contingent on state/organization requirements—EPA cannot guarantee acceptance. Certificates cannot be provided for viewing webinar recordings.

💧 **Small Systems Monthly Webinar Series**

[epa.gov/water-research/small-systems-monthly-webinar-series](https://www.epa.gov/water-research/small-systems-monthly-webinar-series)

February 25: Drinking Water Regulations 101 and Technical Assistance

💧 **Water Research Webinar Series**

<https://www.epa.gov/water-research/water-research-webinars-series>

February 26: Science to Support and Implement Microbial Water Quality Criteria



17th Annual EPA Drinking Water Workshop: Small Systems Challenges and Solutions

September 1-3 in Covington, KY (Cincinnati Area)



Earn Continuing
Education
Contact Hours

Free Workshop Sponsored by



- Monitoring, distribution, source, and treatment topics
- Discussion groups and ask the experts
- Technical talks and demos
- Hands-on training options

Call for Abstracts! (Closes March 26)

Submit a proposal for a technical session talk or poster presentation.

epa.gov/water-research/17th-annual-epa-drinking-water-workshop





Ken Rotert

Rotert.kenneth@epa.gov

Ken is a physical scientist in EPA's Office of Water, Office of Ground Water and Drinking Water, where he has been involved with regulatory review and development and examination of emerging drinking water issues since 1998. His focus has been on distribution systems, cross connections, and microbiological issues, such as *Legionella*, indicator bacteria, fecal contaminants, cyanobacteria, and Ebola.

Public Water System Characteristics that May Affect *Legionella* Occurrence in Building Water Systems

This presentation will highlight EPA's efforts to reduce *Legionella* risks through regulatory revisions, treatment technologies, and research on premise plumbing. An overview of public health impacts, challenges to addressing *Legionella* in drinking water, and potential risk factors in municipal supplies will be included.

Presentation Overview

- Public Health Impacts
- Challenges to Addressing *Legionella* in Drinking Water
- Potential Risk Factors in Municipal Supplies
- EPA Efforts to Reduce *Legionella* Risks
- Other Relevant Drinking Water Regulations
- Some EPA Research on Premise Plumbing and *Legionella*
- Summary

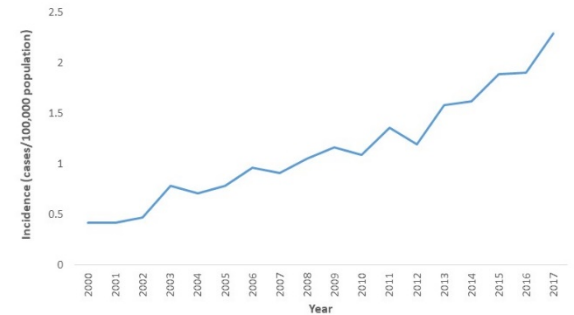
The background of the image is a vibrant blue gradient, transitioning from a lighter blue at the top to a deeper blue at the bottom. The top edge features a realistic, wavy surface of water with several large, detailed bubbles and smaller droplets. Numerous smaller, translucent bubbles are scattered throughout the water, creating a sense of movement and depth. The overall aesthetic is clean, fresh, and natural.

PUBLIC HEALTH IMPACTS

Public Health Impacts

- EPA recognizes legionellosis as a significant and growing public health concern
 - Health departments reported nearly 7,500 cases of Legionnaires' Disease to CDC in 2017 (CDC, 2018)
 - According to a recent National Academies of Science (NAS, 2019) study there are an estimated 52,000-70,000 cases of Legionnaires' Disease annually
 - Adam, et al. (2017) estimated 3,359 Emergency Department visits annually for Legionnaires' Disease, with 91% resulting in hospitalizations
 - According to the NAS 2019 study, an estimated 3-33% of *Legionella* infections lead to death
 - The rate of cases of Legionnaires' Disease reported to CDC increased 5.5 times from 2000-2017

Legionnaires' disease is on the rise in the United States



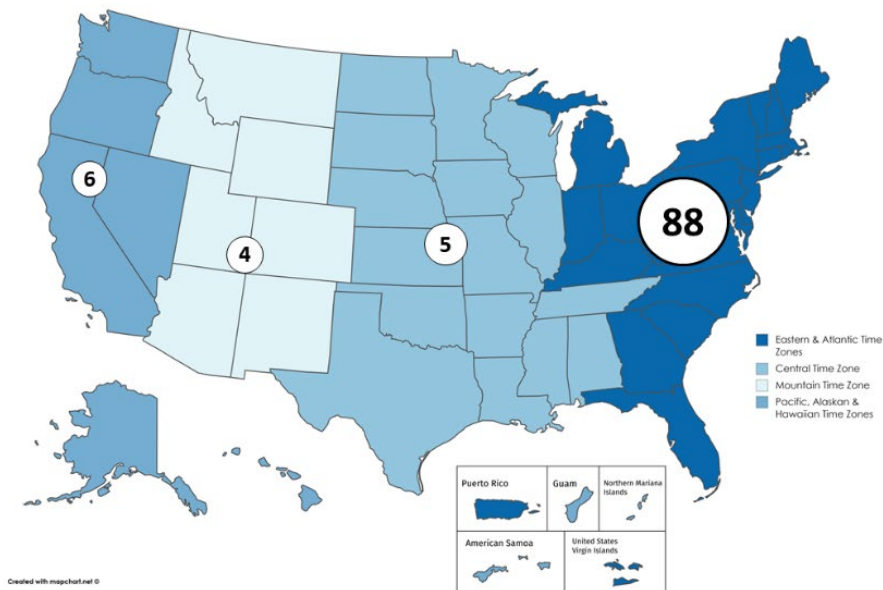
Rate of reported cases increased 5.5 times (2000-2017)

Source: National Notifiable Diseases Surveillance System

Centers for Disease Control and Prevention (CDC)

Public Health Impacts

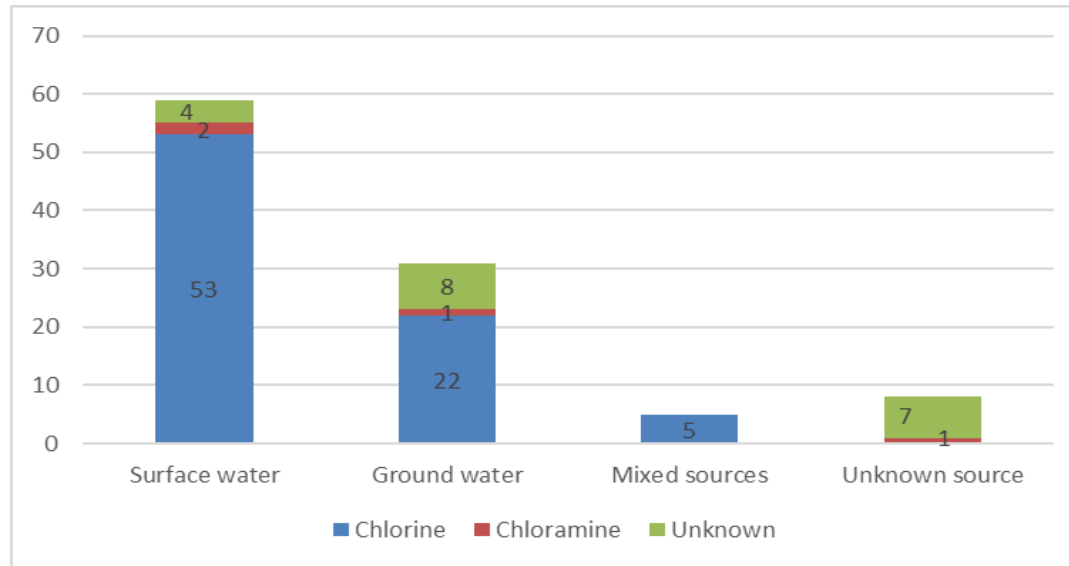
**Number of Reported Legionellosis Outbreaks from 2001-2014
using WBDOSS Data, Grouped by Time Zones* (N=103)**



Source: Tucker, et al., 2018

Public Health Impacts

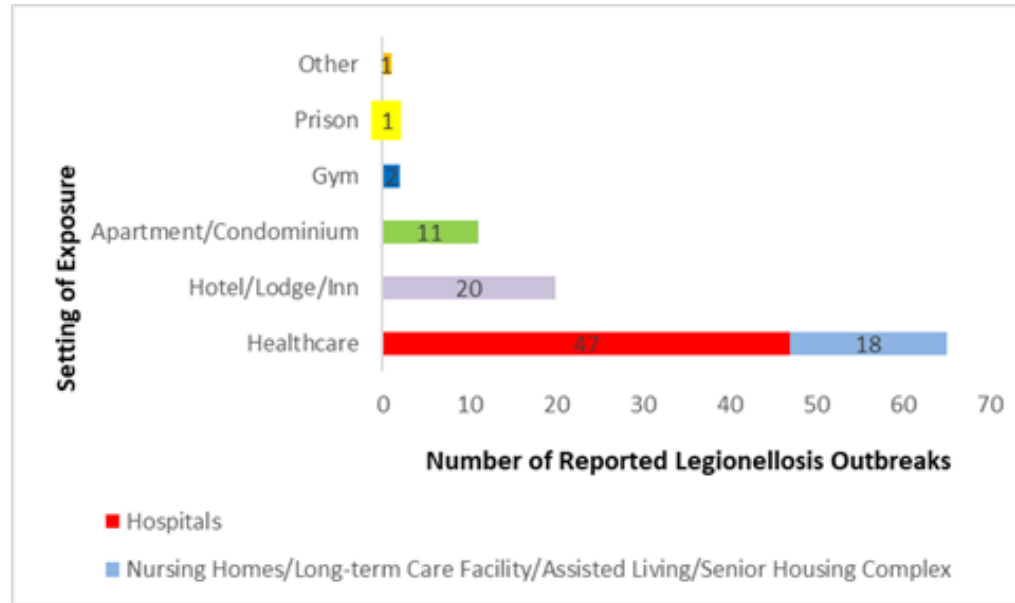
Number of Reported Legionellosis Outbreaks by Source Water and Disinfectant Type from 2001-2014 using the WBD OSS, DBP ICR, UCMR 2, UCMR 3 and CCR Data (N=84)



Source: Tucker, et al., 2018

Public Health Impacts

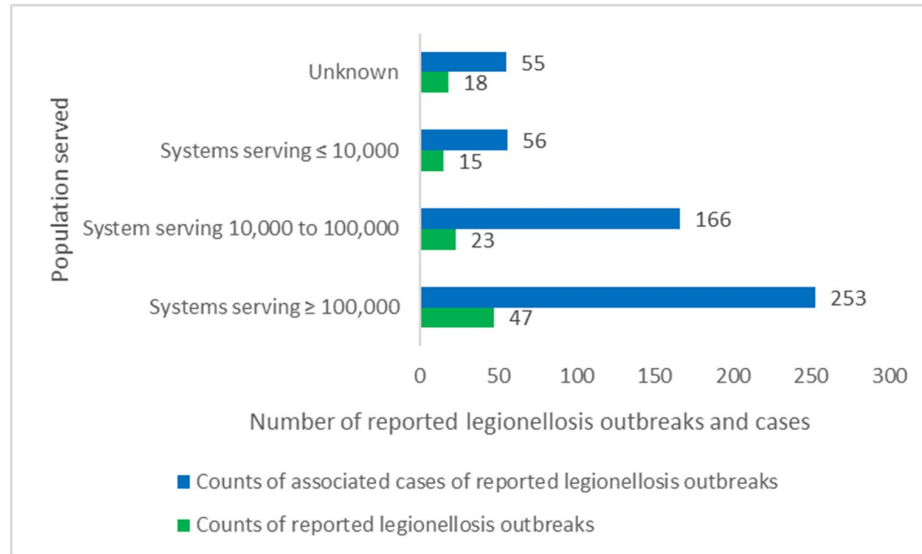
Types of Settings with Reported Legionellosis Outbreaks which Occurred from 2001-2014 using WBDOSSS Data (N=103)



Source: Tucker, et al., 2018

Public Health Impacts

Number of Reported Legionellosis Outbreaks and Outbreak-Associated Cases by Size of the System using WBDOSS and SDWIS Data (N=103)



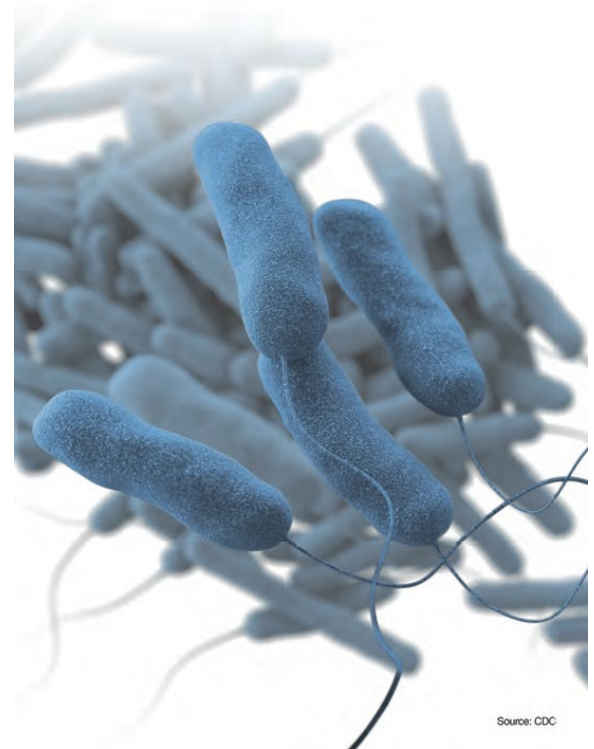
Source: Tucker, et al., 2018

Public Health Impacts

- Most documented drinking water related legionellosis outbreaks and cases are associated with building water systems
- Certain facilities have been implicated in many of the reported outbreaks of Legionnaires' Disease, including health care facilities, hotels, and large institutional buildings
- Public Water Systems can also contribute to *Legionella* outbreaks
 - Cohn et al. (2015) describe two outbreaks in a municipal supply in New Jersey.
- The quality of water entering a building can have an impact on the growth of *Legionella* in building water systems

Challenges to Addressing *Legionella* in Drinking Water

- Public officials, public water system operators and facility managers need better tools to:
 - Assess *Legionella* Risks (most important risk factors)
 - Manage *Legionella* Risks (most effective strategies)
 - Communicate about *Legionella* Risks (most appropriate messaging for subpopulations)





**POTENTIAL RISK FACTORS IN
MUNICIPAL SUPPLIES**

Potential Risk Factors in Municipal Supplies

- Inadequate Disinfectant Residual in the Distribution System
 - Can enable *Legionella* growth in buildings
 - Can be caused by a variety of factors, including high residence time (e.g., in storage tanks), reactions with distribution system materials (e.g., iron), demand from contaminants entering the distribution system, and excess biofilms
 - According to the NAS (2019) an inadequate disinfectant residual contributed to *Legionella* growth in the Flint, Michigan Legionnaire' Disease outbreak
- Disinfectant longevity can depend on the type of secondary disinfectant used
 - Some building water systems provide additional disinfection which may lead to DBP formation concerns if not properly managed

Potential Risk Factors in Municipal Supplies

- Nutrient Availability to Support *Legionella* Growth
 - Nutrients can enter through a variety of sources, including from the source water, and the distribution system (e.g., pipe and storage breaches)
 - Nutrients that can support growth of *Legionella* include iron and carbon
 - Iron is an essential nutrient for *Legionella* that can enter the water in the distribution system as a result of pipe corrosion
 - Iron corrosion in Flint, Michigan was hypothesized to promote *Legionella* growth, which contributed to the Legionnaires' Disease outbreak according to Rhoads et. al., 2017
 - Corrosion control can limit iron release and subsequent growth of *Legionella pneumophila*
 - Carbon can enter from the municipal supply if not adequately removed, and from some distribution system materials (e.g., rubber gaskets) according to Niedevelde et. al., 1986
 - Stagnant water has also been found to have higher concentration of organics according to Wang et. al., 2012
 - Nutrient control may also help to impact the ability of *Legionella* to grow in free-living amoeba according to NAS, 2019

Potential Risk Factors in Municipal Supplies

- High Water Age

- *Legionella* can grow in parts of a distribution system with high water age, such as storage tanks with inadequate water turnover, dead ends, and near closed valves
 - Some finished water storage tanks can have high water age due to tank configuration, infrequent turnover, and water stratification
 - Systems dead legs and parts of the system with oversized pipes can cause high water age
 - While not documented to cause increased *Legionella* concentrations or suspected cases of Legionnaires disease, closed valves were partially responsible for high water age that led to TCR MCL violations in Houston, Texas in 2015 (Smith, 2016)
- Stagnant water can also lead to the growth of protozoa in which *Legionella* reside
- Managing distribution system hydraulics can reduce areas of stagnant water, and help maintain disinfectant residual levels according to NAS, 2019
- Water age can be reduced through several activities, tank management, proper valve operation, elimination of dead legs, and routine flushing

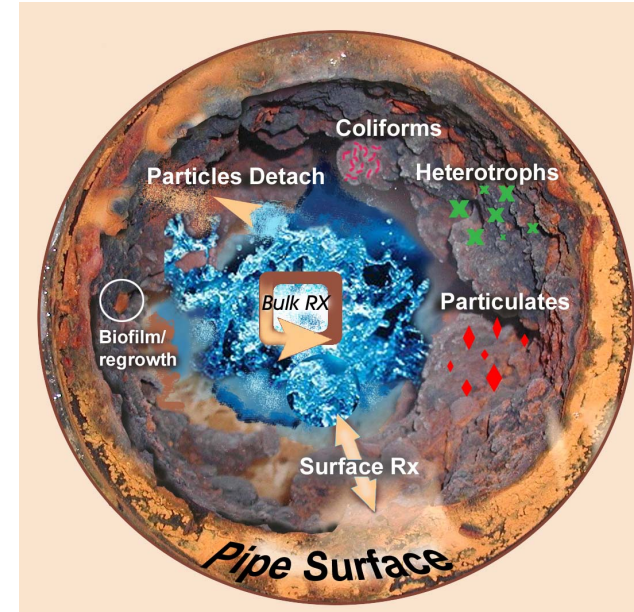
Potential Risk Factors in Municipal Supplies

- Corrosion and Infrastructure Condition
 - Iron corrosion may deplete disinfectant residuals, increase iron bioavailability, increase *Legionella* virulence, enhance biofilm growth, and create a habitat where *Legionella* is protected from disinfection according to NAS, 2019
 - Inadequate corrosion control contributed to the Legionnaires' Disease outbreak in Flint, Michigan according to NAS, 2019
 - Distribution systems (e.g., main breaks) may seed premise plumbing with *Legionella* and lead to Legionnaires' Disease outbreaks or sporadic cases according to NAS, 2019
 - Once *Legionella* enters the system it may grow under favorable conditions
 - The American Society of Civil Engineers (ASCE, 2017) gave U.S. water infrastructure a 'D' rating
 - Many pipes are beyond their expected lifespan, which may increase main breaks, intrusion, and corrosion impacts according to NAS, 2019
 - Distribution system maintenance can reduce many factors that contribute to *Legionella* growth

Potential Risk Factors in Municipal Supplies

- Sediment Accumulation

- Sediments originate from treatment breakthrough, intrusions, corrosion, and other sources, and can accumulate in low flow areas
- Sediments and corrosion products can accumulate in pipes and tanks
- Sediments can provide a niche for the protection of *Legionella* against disinfection and be a source of nutrients that may support *Legionella* growth
- A study of ten states by Lu et al., (2015) found 12/18 *Legionella* positive samples from storage tanks sediments
- The NAS recommends that public water systems have a routine distribution system flushing and cleaning program, and storage tanks should also be inspected and cleaned (NAS, 2019)



A close-up photograph of a water surface with numerous bubbles of various sizes. The water is clear and blue, and the bubbles are bright and reflective. The background is a light blue gradient.

**EPA EFFORTS TO REDUCE *LEGIONELLA*
RISKS**

EPA Efforts to Reduce *Legionella* Risks



- Surface Water Treatment Rule (SWTR) published in 1989
 - Applies to public water systems that use surface water and ground water under the direct influence of surface water
 - Established Maximum Contaminant Level Goals (MCLGs) of zero for *Giardia*, viruses, and *Legionella*
 - Established treatment technique requirements to remove these microbial pathogens to the extent feasible
 - System must practice filtration/disinfection to remove/inactivate *Giardia lamblia* and viruses prior to the first customer in the distribution system;
 - Systems must maintain a detectable residual disinfectant level in the distribution system or maintain of HPC < 500/mL in the distribution

EPA Efforts to Reduce *Legionella* Risks

- SDWA requires EPA to review existing NPDWRs every six years and, if appropriate, revise. EPA calls this process Six-Year Review.
- 3rd Six-Year Review, published in January 2017
 - First review to address microbial and disinfection byproduct regulations
 - Determined the following drinking water regulations are candidates for revision
 - Stage 1 and Stage 2 Disinfectants and Disinfection Byproducts Rules, Surface Water Treatment Rule, Interim Enhanced Surface Water Treatment Rule and Long Term 1 Enhanced Surface Water Treatment Rule

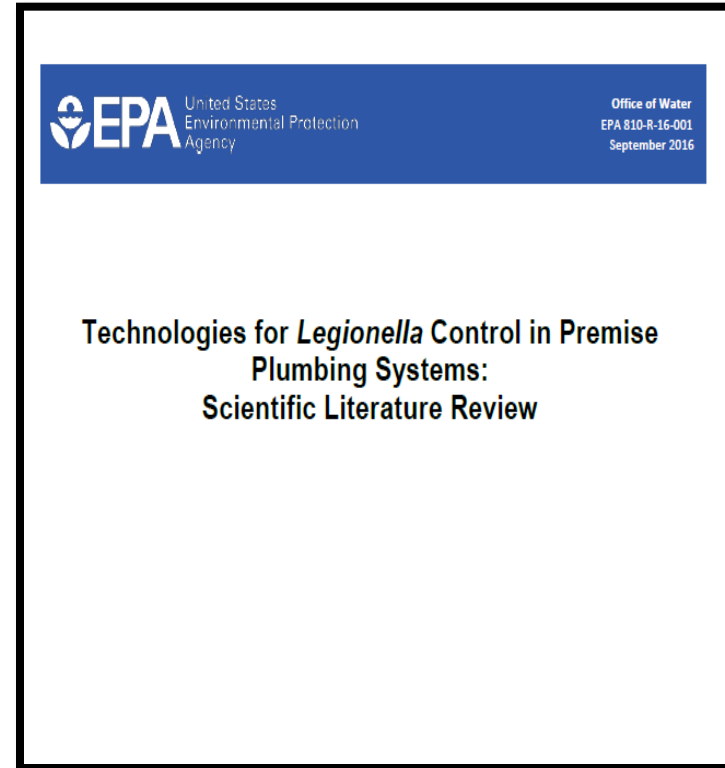
EPA Efforts to Reduce *Legionella* Risks

- The Surface Water Treatment Rule (SWTR) is a candidate for revision
 - Considering a number of pathogens (i.e., *Legionella*, *Mycobacterium avium* Complex, *Pseudomonas*)
- Key elements of SWTR identified for further evaluation:
 - Numerical values for minimum disinfectant residuals in distribution systems
 - Distribution system management to reduce intrusion, leakage, main breaks, cross connections, pathogen growth in storage tanks

EPA Efforts to Reduce *Legionella* Risks



- *Technologies for Legionella Control in Premise Plumbing Systems: Scientific Literature Review, 2016*
 - Provides a characterization of the effectiveness of treatment technologies to control for *Legionella* in premise plumbing based on findings from peer reviewed literature.
 - Technical resource for State, local and tribal officials, facility operators and facility owners to use as they evaluate technologies to respond to the risks associated with *Legionella* growth in premise plumbing systems.





**OTHER RELEVANT DRINKING WATER
REGULATIONS**

Other Relevant Drinking Water Regulations

- Revised Total Coliform Rule
 - Requires monitoring of total coliform and *E. coli* in the distribution system as an indicator of potential treatment upset, or entry of contamination, or biofilm growth within the distribution system
 - Find and fix response actions depending on coliform occurrence
 - A total coliform positive distribution system sample triggers Ground Water Rule mandated source water monitoring



Revised Total Coliform Rule: A Quick Reference Guide

Overview of the Rule

Title	Revised Total Coliform Rule (RTCR) (21 CFR 141.163; February 13, 2015) and 161.163
Purpose	Increase public health protection through the reduction of potential pathways of entry for total coliforms into the distribution system.
General Description	The RTCR establishes a maximum contaminant level (MCL) for total coliforms if total coliforms are detected in first and last tapwater to determine total coliforms that could enter into the distribution system. It requires public water systems (PWS) to perform assessments to identify sanitary defects and subsequently take action to correct them.
Effective Date	The RTCR applies to all PWS.
Other Information	* This document provides a summary of key provisions of the RTCR, to ensure full compliance with the latest regulations at 21 CFR 141.163 and any subsequent rule amendments.

Public Health Benefits

Implementation of the RTCR will result in:

- A decrease in the pathways in which total coliforms can enter the drinking water distribution system.
- Reduction in total coliforms that could reduce the potential risk from waterborne pathogens including bacteria, viruses, parasites, and other associated threats.

Critical Deadlines and Requirements

For Public Water Systems

April 1, 2016

- PWS must develop and submit sampling plans that identify the system's sample collection schedule and all sample sites, including sites for routine and special monitoring.
- PWSs monitoring quarterly or annually must also identify additional routine monitoring sites in their sample site plans.
- Sample site plans are subject to public review and comment.

April 1, 2016

- PWSs must comply with the RTCR requirements unless the state selects an earlier implementation date.

For State Drinking Water Agencies

January 13, 2015

- States submit their primary program review package to the EPA Region, including:
 - Regulatory Crosswalk
 - 40 CFR 141.163 Primary Coliform Checklist
 - 40 CFR 141.163 and 141.164 Reporting and Recordkeeping
 - 40 CFR 141.163 Special Primary Requirements
 - Approved General Sanitation Certification (GSC) (EPA requires all states until February 13, 2015, for the substantial for reduction of total coliforms in primary program review package)
- States must submit a primary program review submission report (PWS) that will plan to submit the first primary program review package by February 13, 2015. The state submission report is submitted to the EPA Region including all of the information required in 40 CFR 141.163.
- It includes (but is not limited to):
 - Details for the submission of the first primary program review package
 - Justification that meets the federal requirements for all relevant reports
 - Confirmation that the state is implementing the RTCR within its scope of its current authority and capabilities
 - An approved critical agreement with the EPA Region

February 13, 2015

- For states with an approved submission, submit complete first program review package to the EPA Region on or before this date.

What are the Major Provisions?


Routine Sampling Requirements

- Total coliforms must be detected in first and last tap water at representative of water quality throughout the distribution system according to a certain sample site plan subject to state review and approval.
- For PWSs monitoring more than one sample per month, collect total coliform samples at regular intervals throughout the month, except that ground water systems serving 1,000 or fewer people may collect all relevant samples on a single day if the samples are taken from different sites.

Other Relevant Drinking Water Regulations

- Ground Water Rule

- Requires source water monitoring either through triggered monitoring or State-directed assessment monitoring to test for the presence of one of three fecal indicators (*E. coli*, enterococci, or coliphage); if sample tests positive, remedial action such as disinfection is required
- Requires sanitary surveys (evaluation of source, treatment, distribution system, pumps, finished water storage, etc.) to identify significant deficiencies (also applies to surface water systems in the Interim Enhanced Surface Water Treatment Rule)
- Remedial action such as disinfection in response to significant deficiencies, as necessary



EPA
United States Environmental Protection Agency

Ground Water Rule Compliance Monitoring: A Quick Reference Guide

Overview of the Rule

Title	Ground Water Rule (GW Rule) (40 CFR 141.604, 141.605, 141.606, 141.607, 141.608, 141.609, 141.610, 141.611, 141.612, 141.613, 141.614, 141.615, 141.616, 141.617, 141.618, 141.619, 141.620, 141.621, 141.622)
Purpose	Protect the GW Rule (GW Rule) from contamination by fecal coliforms, enterococci, and coliphage.
General Description	The GW Rule (GW Rule) is a rule that requires public water systems (PWS) to identify, monitor, and control contamination and requires corrective actions to correct significant deficiencies and address violations of the GW Rule (GW Rule).
Notes	The GW Rule (GW Rule) applies to public water systems (PWS) that use ground water, including community systems, except that it does not apply to PWSs that conduct all of their ground water withdrawals from wells or other ground water under the direct influence of surface water bodies.

Purpose of Compliance Monitoring

- Compliance monitoring is required for PWSs that provide at least 4 mgd of treated or untreated drinking water, use chemical disinfection, membrane filtration, or a State-approved alternative treatment technology, are community and municipal systems, or are public systems.

When Is Compliance Monitoring Required?

- GW Rule provides at least 4 mgd of treated or untreated water that conduct compliance monitoring.
- GW Rule provides at least 4 mgd of treated or untreated water that provide finished water to at least one public water supply system and do not conduct GW Rule triggered source water monitoring.
- The compliance dates for PWSs that provide 4 mgd of treated or untreated water that conduct source water monitoring are as follows:
 - GW Rule with existing ground water sources must notify the State by December 4, 2016, that they provide at least 4 mgd of treated or untreated water and begin compliance monitoring.
 - GW Rule with new ground water sources must notify the State by November 30, 2016, that they provide at least 4 mgd of treated or untreated water and begin compliance monitoring within 30 days.

What are the Compliance Monitoring Requirements for Chemical Disinfection?

GW Rule Section 141.604 (a) (1) (i) (I) (A)

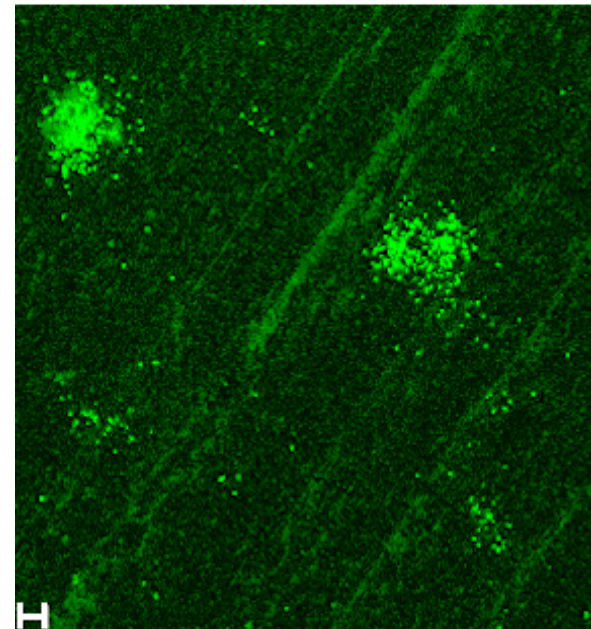
- GW Rule using chemical disinfection and serving 3,000 or more persons must monitor for the required disinfection byproduct (DBP) concentrations and the State approved maximum concentration at or before the first outlet at:
 - GW Rule must monitor on a daily basis and record a grab sample during the hour closest to or within the time specified by the State.
 - If any daily grab sample is less than the minimum disinfection residual concentration, the system must take follow-up actions every four hours until the residual meets or exceeds the 2000-4000 minimum concentration.
 - These systems must have the option to monitor continuously.
 - If the DWTR requires continuous, the system must meet the monitoring requirements for GW Rule serving greater than 3,000 persons (see below).
- GW Rule must monitor at a 2000-4000 minimum.



**SOME EPA RESEARCH ON PREMISE
PLUMBING AND *LEGIONELLA***

Some EPA Research on Premise Plumbing and *Legionella*

- Efficacy of Treatment for the Prevention and Decontamination of *Legionella* in Drinking Water
- Occurrence of *Legionella* and Other Opportunistic Pathogens in Plumbing Systems and Drinking Water Storage Tanks
- Molecular and Culture-Based Methods for the Enumeration of *Legionella*



Some EPA Research on Premise Plumbing and *Legionella*

- Evaluation of *Legionella* Persistence Related to Distribution System Surfaces, Water Quality Parameters, and Other Biotic and Abiotic Factors
- Water Quality Assessment of Model Home Plumbing System
- *Legionella* as an Indicator of Microbial Contamination of Distribution





SUMMARY

Summary

- Legionellosis is a serious and growing health concern
- Challenges to addressing *Legionella* contamination exist regarding assessing, managing and communicating the risks
- According the 2019 NAS report, municipal water supplies can reduce some *Legionella* -related risks by certain management practices and controlling several water quality conditions that can impact *Legionella* occurrence in buildings (NAS, 2019)
- EPA has taken some steps to address *Legionella* and related concerns
- EPA continues to research concerns related to *Legionella*

References

- Centers for Disease Control and Prevention. (2018). *Legionella* (Legionnaires' Disease and Pontiac Fever): History, Burden, and Trends. <https://www.cdc.gov/legionella/about/history.html>
- NAS. (2019). Management of *Legionella* in Water Systems. Washington, DC: The National Academies Press. <https://doi.org/10.17226/25474>.
- Adam, E.A., S.A. Collier, K.E. Fullerton, J.W. Gargano, and M.J. Beach. (2017). Prevalence and direct costs of emergency department visits and hospitalizations for selected diseases that can be transmitted by water, United States. *Journal of water and health*, 15(5), pp.673-683.
- Tucker, N., H. Holsinger, S. Regli, K. Rotert, M. Tricas, K. Benedict, K. Fullerton, V. Roberts, and J. Yoder. (2018). Characterization of reported legionellosis outbreaks in drinking water systems — United States, 2001–2014.

References

- Cohn, P.D., J.A. Gleason, E. Rudowski, S.M. Tsai, C.A. Genese and J.A. Fagliano. (2015). Community outbreak of legionellosis and an environmental investigation into a community water system. *Epidemiology & Infection*, 143(6): 1322-1331.
- Rhoads, W.J., E. Garner, P. Ji, N. Zhu, J. Parks, D.O. Schwake, A. Pruden, and M.A. Edwards. (2017). Distribution system operational deficiencies coincide with reported legionnaires' disease clusters in Flint, Michigan. *Environmental Science & Technology*, 51(20), pp.11986-11995.
- Niedevelde, C.J., F.M. Pet, and P.L. Meenhorst. (1986). Effects of rubbers and their constituents on proliferation of *Legionella pneumophila* in naturally contaminated hot water. *Lancet*. July 26: 180-184.

References

- Wang, H., S. Masters, Y. Hong, J. Stallings, J. O. Falkinham, M. A. Edwards, and A. Pruden. (2012). Effect of disinfectant, water age, and pipe material on occurrence and persistence of *Legionella*, mycobacteria, *Pseudomonas aeruginosa*, and two amoebas. *Environ. Sci. Technol.* 46(21):11566-11574.
- Smith, K. S. (2016). Disinfectant Residual Management - Utility Perspective & Case Study. Proceedings of the American Water Works Association Annual Conference and Exposition, June 21, 2016.
- American Society of Civil Engineers (ASCE). (2017). Infrastructure report card—Drinking water. <https://www.infrastructurereportcard.org/wp-content/uploads/2017/01/Drinking-Water-Final.pdf>.

References

- Lu J., I. Struewing, S. Yelton, and N. Ashbolt. (2015). Molecular survey of occurrence and quantity of *Legionella* spp., *Mycobacterium* spp., *Pseudomonas aeruginosa* and amoeba hosts in municipal drinking water storage tank sediments. J. Appl. Microbiol. 119(1):278-288.
- EPA. (2016). Technologies for *Legionella* control in premise plumbing systems: Scientific literature review. Washington, DC: EPA.



Maura Donohue

Donohue.maura@epa.gov

Maura is a research chemist in EPA's Office of Research and Development, Center of Environmental Solutions and Emergency Response. For the past ten years, her research has been centered around microbial control and disinfection byproducts. Her current efforts are focused on examining the distribution of *Legionella* and NTM and the water quality characteristics that support their persistence in the built environment. Maura has a Ph.D in chemistry from American University and a B.A. in biological sciences from Elms College.

Impact of Chlorine and Chloramine on the Detection and Quantification of *Legionella pneumophila* and *Mycobacterium* species

Potable water can be a source of transmission for legionellosis and nontuberculous mycobacteria (NTM) infection and diseases. This presentation will investigate the influence of disinfectant type and total chlorine residual (TCIR) on the detection and concentration of the five leading pathogens associated with these infections and diseases.



Impact of Chlorine and Chloramine on the Detection and Quantification of *Legionella pneumophila* and *Mycobacterium* Species

Maura J. Donohue,^a Steve Vesper,^a Jatin Mishra,^b Joyce M. Donohue^c

^aU.S. Environmental Protection Agency, Cincinnati, Ohio, USA
^bU.S. Environmental Protection Agency, Dallas, Texas, USA
^cU.S. Environmental Protection Agency, Washington, DC, USA

ABSTRACT Potable water can be a source of transmission for legionellosis and nontuberculous mycobacterium (NTM) infections and diseases. Legionellosis is caused largely by *Legionella pneumophila*, specifically serogroup 1 (Sg1). *Mycobacterium avium*, *Mycobacterium intracellulare*, and *Mycobacterium abscessus* are three leading species associated with pulmonary NTM disease. The estimated rates of these diseases are increasing in the United States, and the cost of treatment is high. Therefore, a national assessment of water disinfection efficacy for these pathogens was needed. The disinfectant type and total chlorine residual (TCR) were investigated to understand their influence on the detection and concentrations of the five pathogens in potable water. Samples ($n = 358$) were collected from point-of-use taps (cold or hot) from locations across the United States served by public water utilities that disinfect with chlorine or chloramine. The bacteria were detected and quantified using specific primer and probe quantitative-PCR (qPCR) methods. The total chlorine residual was measured spectrophotometrically. Chlorine was the more potent disinfectant for controlling the three mycobacterial species. Chloramine was effective at controlling *L. pneumophila* and Sg1. Plotting the TCR associated with positive microbial detection showed that an upward TCR adjustment could reduce the bacterial count in chlorinated water but was not as effective for chloramines. Each species of bacteria responded differently to the disinfectant type, concentration, and temperature. There was no unifying condition among the water characteristics studied that achieved microbial control for all. This information will help guide disinfectant decisions aimed at reducing occurrences of these pathogens at consumer taps and is related to the disinfectant type and TCR.

IMPORTANCE The primary purpose of tap water disinfection is to control the presence of microbes. This study evaluated the role of disinfectant choice on the presence at the tap of *L. pneumophila*, its Sg1 serogroup, and three species of mycobacteria in tap water samples collected at points of human exposure at locations across the United States. The study demonstrates that microbial survival varies based on the microbial species, disinfectant, and TCR.

KEYWORDS chlorine, chloramine, drinking water, Legionella, Mycobacterium, total chlorine residual

Legionella and *Mycobacterium* are two genera of waterborne environmental bacteria that affect human health by causing the respiratory diseases legionellosis (Legionnaires' disease and Pontiac fever) (1) and nontuberculous mycobacterium (NTM) infections and diseases (2), respectively. Potable water is often suspected or identified as the cause of individual cases or a cluster of cases (an outbreak). Outbreaks for both genera

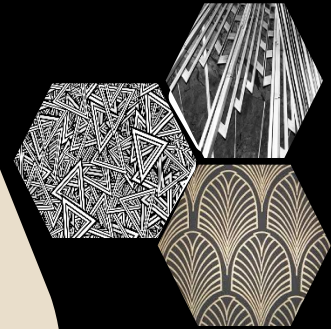


SEPA RTP/PAW/ERC Library

Citation Donohue MJ, Vesper S, Mishra J, Donohue JM. 2019. Impact of chlorine and chloramine on the detection and quantification of *Legionella pneumophila* and *Mycobacterium* species. *Appl Environ Microbiol* 85(25):e01942-19. <https://doi.org/10.1128/AEM.01942-19>.

Editor Christopher A. Elmer, Centers for Disease Control and Prevention. This is a work of the U.S. Government and is not subject to copyright protection in the United States; foreign copyrights may apply. Address correspondence to Maura J. Donohue, Donohue@epa.gov.

Received 26 August 2019
Accepted 1 October 2019
Accepted manuscript posted online 11 October 2019
Published 27 November 2019



A Tale of Two Bacterium...

Legionellaceae

- Legionella (Genus)
 - Gram negative bacteria (Gammaproteobacteria)
 - Flagella rod (2-20 μm)
 - Slow grower (3 to 10 days)
 - Majority of species will grow in free-living amoebae
 - Aerobic, L-cysteine and iron salts are required for in vitro growth, pH: 6.8 to 7, T: 25 to 43 $^{\circ}\text{C}$
 - ~65 species
 - Pathogenic or potentially pathogenic for human

Mycobacteriaceae

- Mycobacterium (Genus)
 - Nontuberculous Mycobacterium (NTM)
 - *M. avium-intracellulare* complex (MAC)
 - Gram positive bacteria
 - Rod shape (1-10 μm)
 - Non-motile, spore-forming, aerobic
 - Rapid to Slow grower (1 week to 8 weeks)
 - ~156 species
 - Some species capable of causing disease



NTM from Environmental Microorganism to Opportunistic Opponent

Genus

156 Species

Disease

NTM = Nontuberculous Mycobacteria

MAC = *M. avium* Complex

Mycobacterium spp.

Mycobacterium
Mycobacterium abscessus
Mycobacterium africanum
Mycobacterium agri
Mycobacterium aichiense
Mycobacterium algericum
Mycobacterium alsense
Mycobacterium alvei
Mycobacterium angelicum
Mycobacterium anyangense
Mycobacterium arabiense
Mycobacterium aromatiivorans
Mycobacterium arsiense
Mycobacterium arupense
Mycobacterium asiaticum
Mycobacterium aurum
Mycobacterium austroafricanum
Mycobacterium avium
Mycobacterium bacteremicum
Mycobacterium boenickei
Mycobacterium botniense
Mycobacterium bouchedurhonense
Mycobacterium bourgelatii
Mycobacterium bovis
Mycobacterium brisbanense
Mycobacterium brumae
Mycobacterium canariense
Mycobacterium caprae
Mycobacterium celatum
Mycobacterium celeriflavum
Mycobacterium chelonae
Mycobacterium chitae
Mycobacterium chlorophenicum
Mycobacterium chubuense
Mycobacterium colombiense
Mycobacterium conceptionense
Mycobacterium confluentis
Mycobacterium conspicuum
Mycobacterium coolii
Mycobacterium cosmeticum
Mycobacterium crocinum
Mycobacterium doricum

Mycobacterium duvalii
Mycobacterium elephantis
Mycobacterium europaeum
Mycobacterium fallax
Mycobacterium farcinogenes
Mycobacterium flavescens
Mycobacterium florentinum
Mycobacterium fluoranthenorans
Mycobacterium fortuitum
Mycobacterium franklinii
Mycobacterium frederiksbergense
Mycobacterium gadium
Mycobacterium gastrii
Mycobacterium genavense
Mycobacterium gilvum
Mycobacterium goodii
Mycobacterium gordoniae
Mycobacterium haemophilum
Mycobacterium hassiacum
Mycobacterium heckeshornense
Mycobacterium heidelbergense
Mycobacterium hiberniae
Mycobacterium hippocampi
Mycobacterium hodleri
Mycobacterium holsaticum
Mycobacterium houstonense
Mycobacterium immunogenum
Mycobacterium insubricum
Mycobacterium interjectum
Mycobacterium intermedium
Mycobacterium intracellulare
Mycobacterium iranicum
Mycobacterium kansasii
Mycobacterium komossense
Mycobacterium koreense
Mycobacterium kubicae
Mycobacterium kumamotoense
Mycobacterium kyorinense
Mycobacterium lacus
Mycobacterium lentificum
Mycobacterium leprae
Mycobacterium lepraemurium

Mycobacterium litorale
Mycobacterium llatzerense
Mycobacterium madagascariense
Mycobacterium mageritense
Mycobacterium malmoense
Mycobacterium mantonii
Mycobacterium marinum
Mycobacterium massiliense
Mycobacterium microti
Mycobacterium minnesotense
Mycobacterium monacense
Mycobacterium montefiorensis
Mycobacterium moriokaense
Mycobacterium mucogenicum
Mycobacterium murale
Mycobacterium neoaurum
Mycobacterium nebraskense
Mycobacterium neworleansense
Mycobacterium nonchromogenicum
Mycobacterium noviomagense
Mycobacterium novocastrense
Mycobacterium pallens
Mycobacterium palustre
Mycobacterium paraense
Mycobacterium paraffinicum
Mycobacterium parafortuitum
Mycobacterium paragordoniae
Mycobacterium paraintracellulare
Mycobacterium parakoreense
Mycobacterium parascrofulaceum
Mycobacterium paraseoulense
Mycobacterium paratuberculosis
Mycobacterium parvum
Mycobacterium phlei
Mycobacterium phocaicum
Mycobacterium pinnipedii
Mycobacterium porcinum
Mycobacterium poriferae
Mycobacterium pseudoshottsii
Mycobacterium psychrotolerans

Mycobacterium pulveris
Mycobacterium pyrenivorans
Mycobacterium rhodasiae
Mycobacterium ryadhense
Mycobacterium rufum
Mycobacterium rutilum
Mycobacterium salmoniphilum
Mycobacterium saopaulense
Mycobacterium saskatchewanense
Mycobacterium scrofulaceum
Mycobacterium sediminis
Mycobacterium senegalense
Mycobacterium senuense
Mycobacterium seoulense
Mycobacterium septicum
Mycobacterium setense
Mycobacterium sherrisii
Mycobacterium shimoides
Mycobacterium shinjuense
Mycobacterium shottsii
Mycobacterium simiae
Mycobacterium smegmatis
Mycobacterium sphagni
Mycobacterium stomatepiae
Mycobacterium szulgai
Mycobacterium terrae
Mycobacterium thermoresistibile
Mycobacterium timonense
Mycobacterium tokalaense
Mycobacterium triplex
Mycobacterium triviale
Mycobacterium tuberculosis
Mycobacterium tusciae
Mycobacterium ulcerans
Mycobacterium vaccae
Mycobacterium vanbaalenii
Mycobacterium vulneris
Mycobacterium wolinskyi
Mycobacterium xenopi
Mycobacterium yongonense

Clinically Relevant Species

M. avium, *M. intracellulare*, *M. fortuitum*, *M. chelonae*, *M. kansasii*, *M. abscessus*, etc.

- Pulmonary NTM lung disease
- Chronic bronchopulmonary disease
- Cervical or other lymphadenitis
- Skin and soft tissue diseases
- Disseminated infections
- Catheter-related infections



Legionellosis: Respiratory Disease

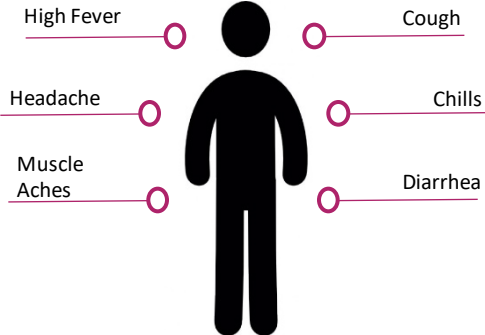
Disease

Legionellosis = **pneumonia**

- Legionaries' Disease (severe)
- Pontiac Fever (mild)

Signs/Symptoms

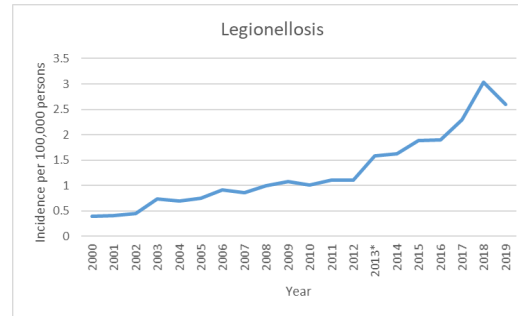
Pneumonia
(Signs/Symptoms)



National Notifiable Disease Surveillance System (NNDSS)

2019 National Reportable Disease List: contained the names of over 110 Diseases/Microorganisms

Number of Cases Reported in 2019:
7,802 cases



LEGIONELLOSIS.

Incidence,* by year — United States, 2000–2019, Source NNDSS



Annual Cost of Treatment in the U.S.



Number of Hospitalization/year
8,000-18,000 cases (Marston, (1997))
avg(13,000)

Total Hospitalization Cost:
\$433,758,000

Collier, S.A. et al 2012:
Direct healthcare costs of selected disease primarily or partially transmitted by water. *Epidemiology Infection*, 140, p2003-2013

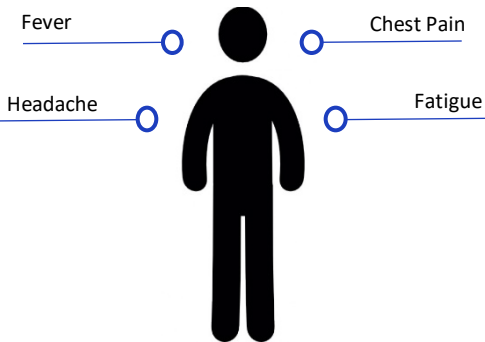
Nontuberculous Mycobacteria Infection/Disease: Primarily Respiratory Diseases



Infection/Disease

- Pulmonary NTM lung disease
- Chronic bronchopulmonary disease
- Cervical or other lymphadenitis
- Skin and soft tissue diseases
- Disseminated infections
- Catheter-related infections

Signs/Symptoms



State Health Departments

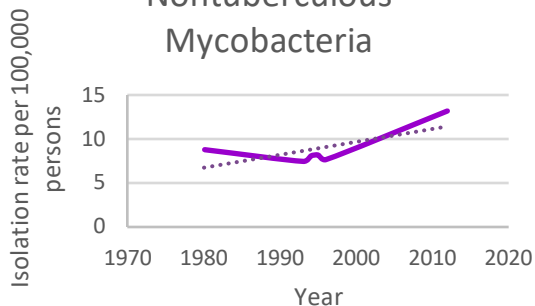
Laboratory Reports

*Report is defined as the presence of culturable NTM from a human specimen (Lavage, Sputum, Blood, and/or Tissue)

Number of Cases Reported in 2010:

Est 86,244 cases

Nontuberculous Mycobacteria



NONTUBERCULOUS MYCOBACTERIA.

Isolation Rate,* by year — United States, 1980–2013,

Sources: Good et al. (1980), CDC, NTM 1993-1996 report (1999), Donohue et al. (2016)



Annual Cost of Treatment in the U.S.



Number of
Hospitalization/year
16,286 cases: 2007

Total Hospitalization Cost:
\$425,788,469

Collier, S.A. et al 2012:

Direct healthcare costs of selected disease primarily or partially transmitted by water. *Epidemiology Infection*, **140**, p2003-2013

Number of NTM Cases
est 86,244 cases: 2010

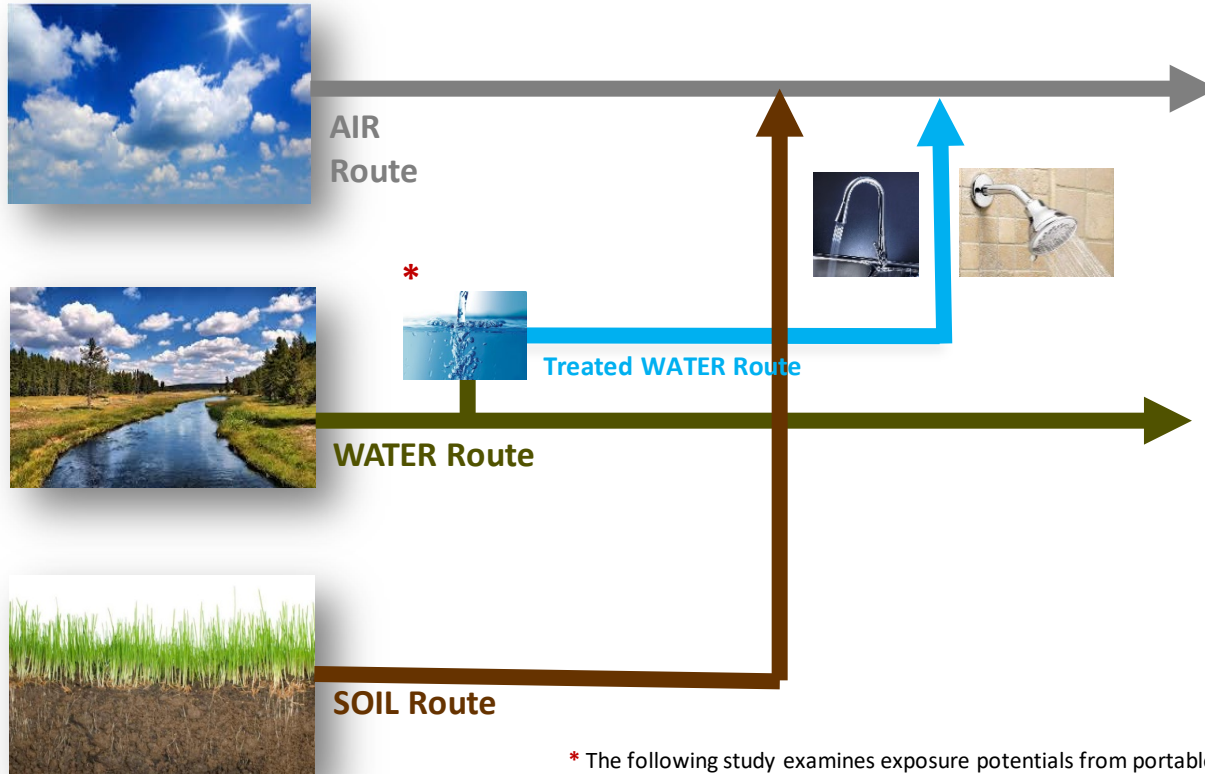
Total Hospitalization Cost:
\$815,098,690

Stroll to S.E. et al 2015: The Burden of Pulmonary Nontuberculous Mycobacterial Disease in the United States. *AnnalsATS*, **12**, p1458-1464



Exposure Routes: Environmental Sources

Legionella pneumophila and *Mycobacterium avium* are microorganisms of the natural environment found in soil and water.



* The following study examines exposure potentials from portable water

What Is the Purpose of this Study?



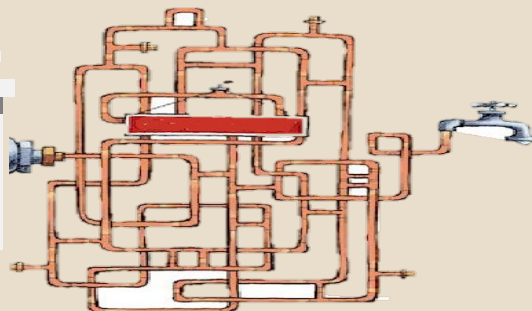
Source Water

King et al. 2016: STOEN



Clear Well

King et al. 2016: STOEN



Distribution

In Progress



Houses/Building

Point of Use

Donohue et al 2019: JAM & AEM

- The purpose of this study was to understand what is occurring at point of use, where human exposure could potential occur.



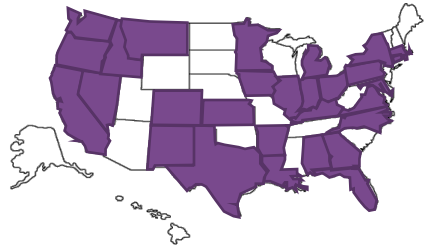
Study Design

46 States and Territories

Structure/ Point of Use
358 Samples

5 qPCR Assays

Water Quality Testing



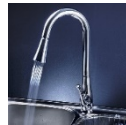
Cold/Hot Water



Houses



Buildings



- *Legionella pneumophila*
Donohue et al. 2014
- *L. pneumophila* Sg1
Merault et al. 2011
- *Mycobacterium avium*
Chen et al. 2015
- *Mycobacterium intracellulare*
Chen et al. 2015
- *Mycobacterium abscessus*
Steindor M. et al. 2015



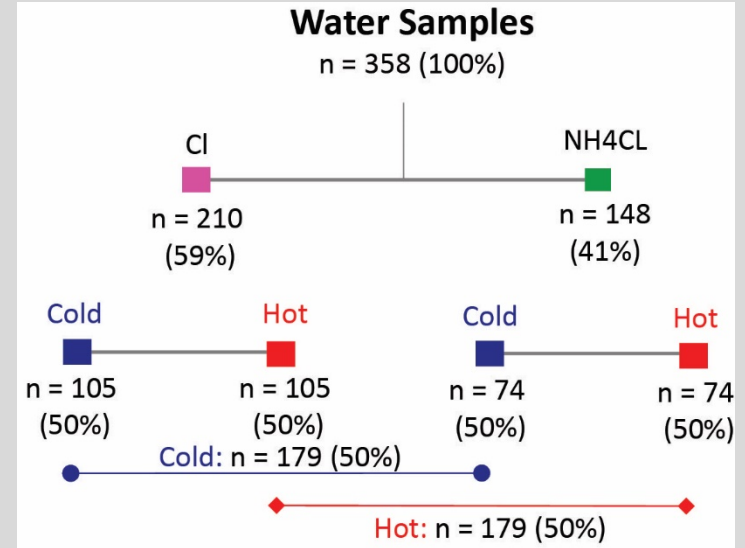
- Detection Frequency (FD)
- Persistence
- Concentration

- Total Chlorine
DPD Total Chlorine Test
- Monochloramine
Monochlor F Test
- Temperature
Cold water line
Hot water line
- Heterotrophic Plate Counts (HPC)
Standard Method 9215

Sampling Time Frame : 2011 – 2017

Variables Evaluated

- Chlorine (Cl) versus Chloramine (CLM)
- At the tap disinfectant residuals (Total Chlorine Test) – Temperature (Cold vs Hot)
- *L. pneumophila* (Lp) – Mycobacterium spp. (Myco) includes MA/MI/Mab



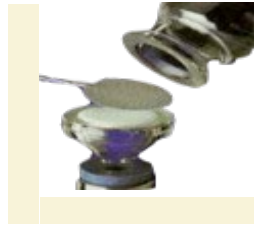
Molecular Testing: qPCR

Method

Water



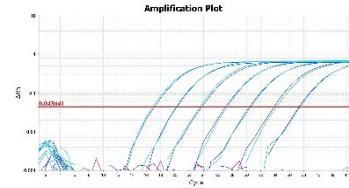
Membrane Filtration
Polycarbonate 0.4 µm



DNA Extraction
Bead Beating
DNA precipitation

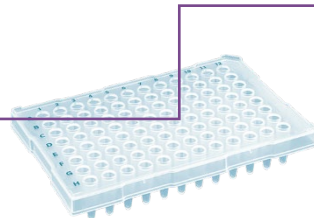


qPC
40 cycles
1hr 45 min



Assays

- *Legionella pneumophila*
- *L. pneumophila* Sg1
- *Mycobacterium avium*
- *Mycobacterium intracellulare*
- *Mycobacterium abscessus*



1 Well = 1 Reaction

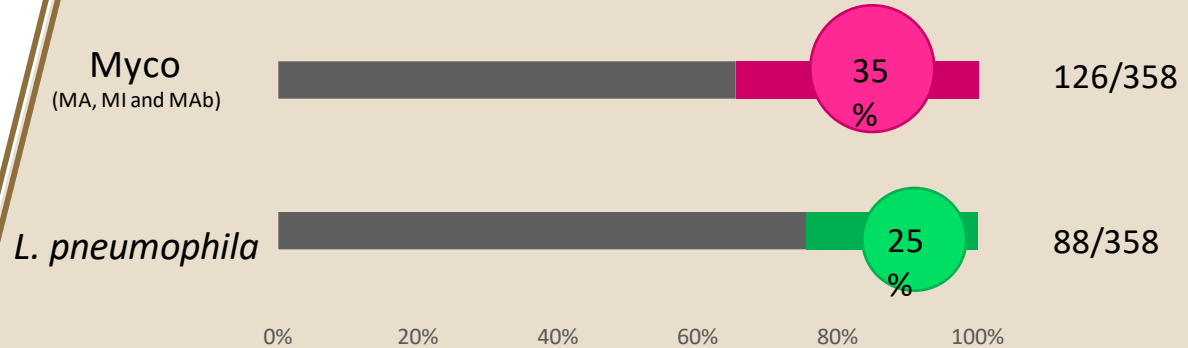
96 plate well: Well Format

- Assay/Mastermix
- Primer/Probes
- Template(DNA/ddH₂O)
- Internal Control

Study: Percent Positive

Point of Use

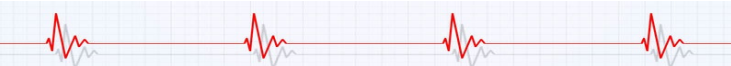
Houses/Building





Is
L. pneumophila/
Mycobacteria
spp. Occurrence
 Influenced by
 Disinfectant
 Choice?

Detection Frequency

Yes, detection frequency for *M. avium* and *M. abscessus* were significantly detection more often in chloramine treated water.

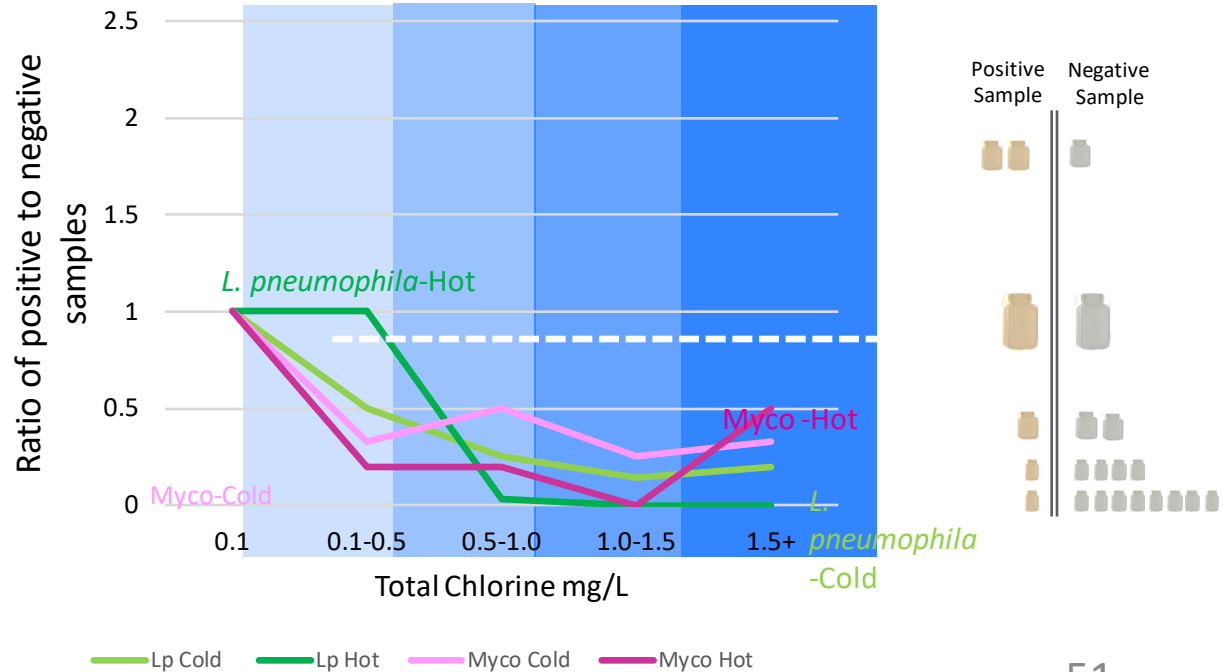


Species-Serogroup	Chlorine	Chloramine	Chi-Square p-value
	Number of Positive Samples (Percent) N = 210	Number of Positive Samples (Percent) N = 148	
All Samples	N = 210	N = 148	
<i>L. pneumophila</i>	55 (26)	32 (22)	NS
<i>L. pneumophila Sgl</i>	18 (9)	7 (5)	NS
<i>M. avium</i>	26 (12)	32 (22)	P = 0.02
<i>M. intracellulare</i>	44 (21)	29 (20)	NS
<i>M. abscessus</i>	19 (9)	25 (17)	P = 0.03
Cold Water Line	N = 105	N = 74	
<i>L. pneumophila</i>	29 (28)	17 (24)	NS
<i>L. pneumophila Sgl</i>	8 (8)	4 (6)	NS
<i>M. avium</i>	15 (14)	16 (22)	NS
<i>M. intracellulare</i>	21 (20)	16 (22)	NS
<i>M. abscessus</i>	11 (10)	13 (18)	NS
Hot Water Line	N = 105	N = 74	
<i>L. pneumophila</i>	27 (26)	16 (22)	NS
<i>L. pneumophila Sgl</i>	10 (9)	3 (4)	NS
<i>M. avium</i>	11 (10)	16 (22)	NS
<i>M. intracellulare</i>	23 (22)	13 (19)	NS
<i>M. abscessus</i>	8 (8)	12 (17)	NS

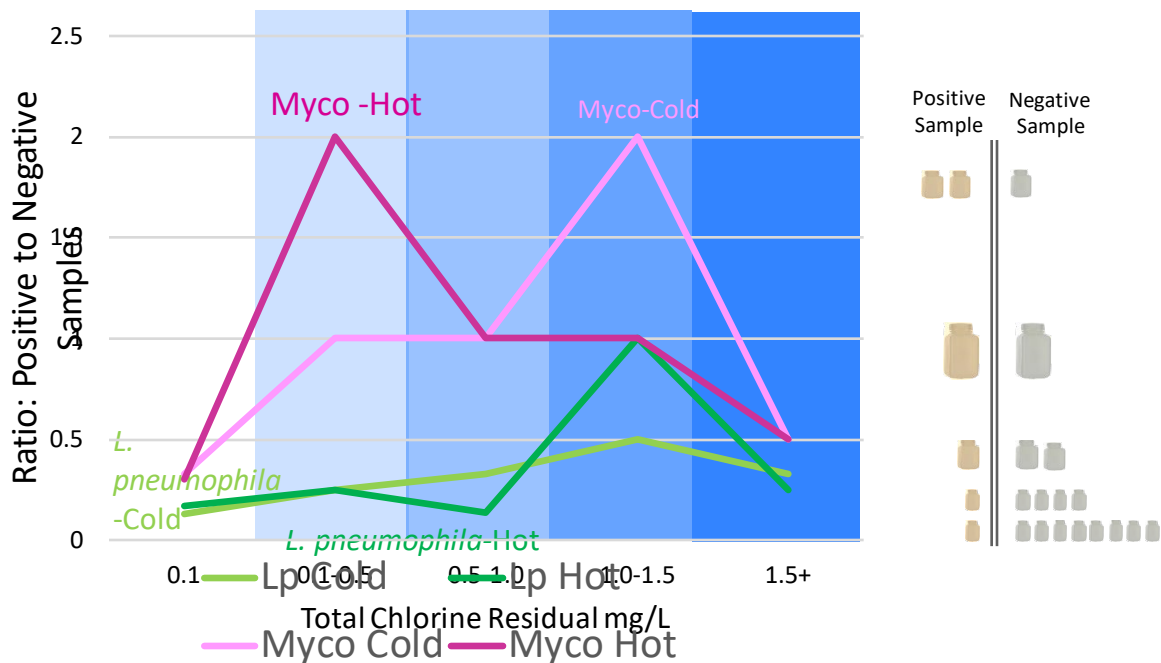
Chlorine: Does the Total Chlorine Residual (TCLR) Concentration Influence *L. pneumophila* / *Mycobacterium* spp. Detection Frequency?

- As the at the tap concentration of the residual increases, the less likely it is to find a positive sample.
- This is true for all five bacteria.



Chloramine: Does the Residual (TCLR) Concentration Influence *L. pneumophila*/*Mycobacterium* spp. Detection Frequency?

- Each Bacteria responded differently to the increasing residual.
- Legionella was rarely detected at the lower residual concentrations but despite this positive detections increase at the higher residual levels.
- Myco-Cold and Myco-Hot each responded differently to the residual concentration.

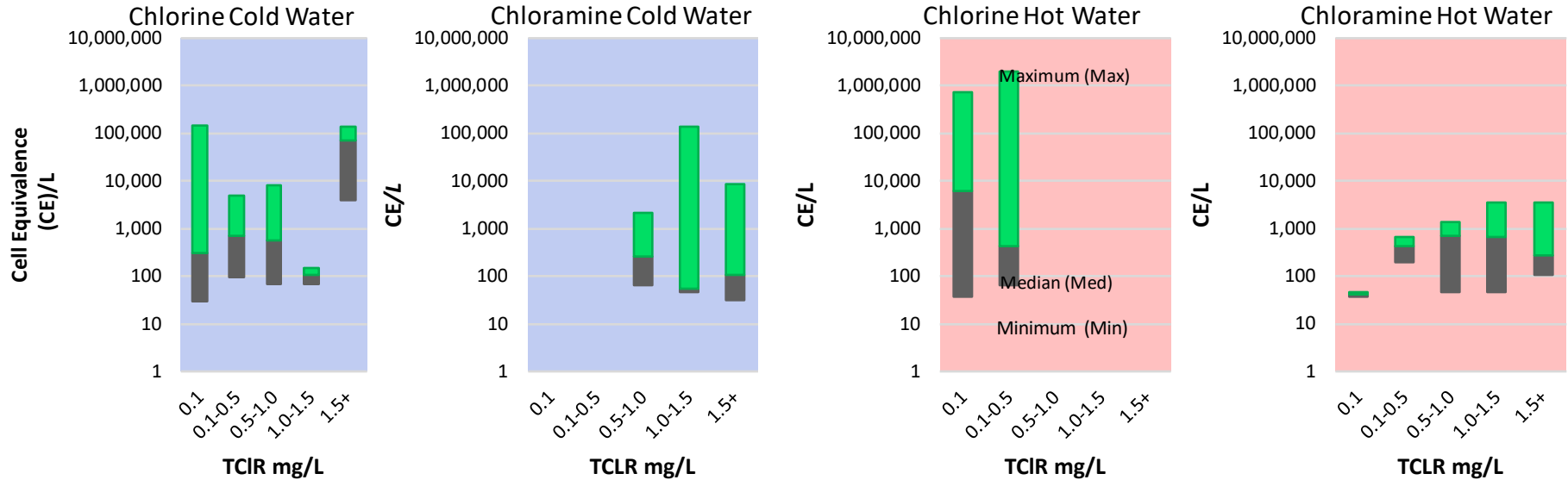


Does *L. pneumophila*/Mycobacterium spp. Concentration Differ by Disinfectant Residual Choice?

- Yes, significant differences were observed for *L. pneumophila* in both cold and hot water line samples and for *M. intracellulare* (cold water line samples).
- Significantly higher amounts of *L. pneumophila* are observed in Chlorine treated water, especially hot water illustrating the effectiveness of chloramine in controlling for legionella.
- Significantly higher amounts of *M. intracellulare* are observed in Chloramine treated water suggesting better control with chlorine.

Species-Serogroup	Chlorine	Chloramine	Mann-Whitney U
	Median (CE/L)	Median (CE/L)	p-value
All samples	N = 210	N=148	NS
<i>L. pneumophila</i>	581	132	P = <0.001
<i>L. pneumophila Sg1</i>	15,721	863	NS
<i>M. avium</i>	603	1,243	NS
<i>M. intracellulare</i>	487	661	NS
<i>M. abscessus</i>	1,339	2,157	NS
Cold Water Line	N = 105	N = 74	
<i>L. pneumophila</i>	341	82	P = 0.04
<i>L. pneumophila Sg1</i>	938	570	P = 0.05
<i>M. avium</i>	616	1,880	NS
<i>M. intracellulare</i>	359	928	P = 0.02
<i>M. abscessus</i>	1,113	834	NS
Hot Water Line	N = 105	N = 74	
<i>L. pneumophila</i>	4,201	187	P = 0.01
<i>L. pneumophila Sg1</i>	85,316	942	NS
<i>M. avium</i>	425	761	NS
<i>M. intracellulare</i>	542	602	NS
<i>M. abscessus</i>	9,048	17,304	NS

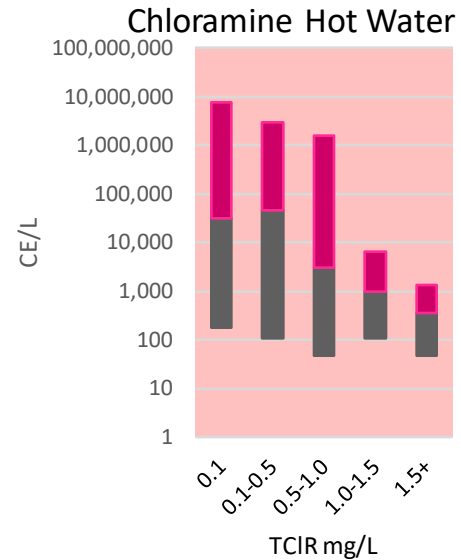
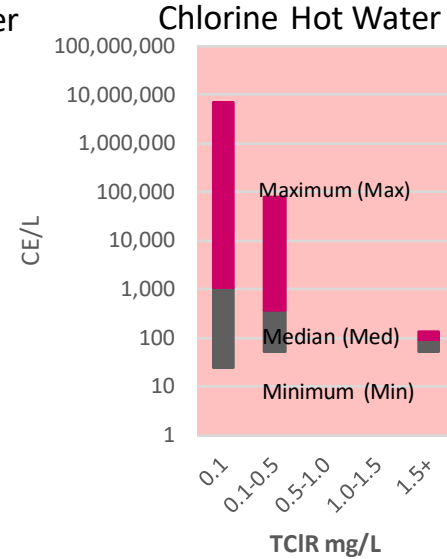
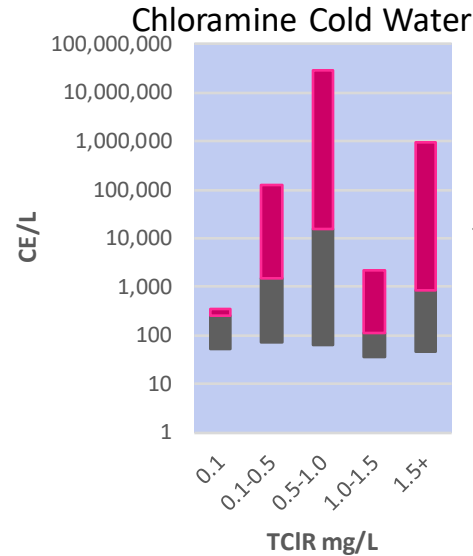
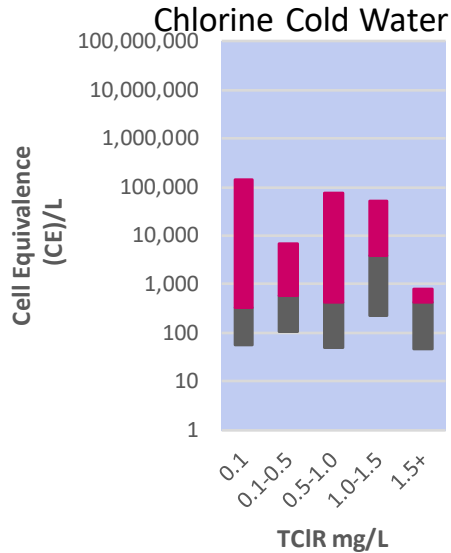
Does Residual Concentration Influence *L. pneumophila* Concentration?



- The residual type and residual concentration have independent impacts on *L. pneumophila*.
- It depend on the context

- Chlorine's (CL) impact on *L. pneumophila* concentrations is dose dependent based on the residual concentration.
- CLM impact on *L. pneumophila* isn't as dose dependent. 54

Does Residual Concentration Influence *Mycobacterium* spp. Concentration?



- Chlorine (CL) in cold water “keeps the lid on” the *Mycobacterium* spp.
- However, CL plus hot water does have a dose dependent impact on *Mycobacterium* spp. concentrations.

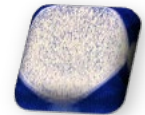
- CLM in cold water doesn't appear to impact on the *Mycobacterium* spp. species concentration.
- CLM plus heat does impact *Mycobacterium* spp. in a dose dependent manor.



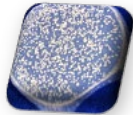
Chloramine: Heterotrophic Plate Counts

Many of the *L. pneumophila* and *Mycobacterium spp.* detections are in water that has a high viable bacteria load.

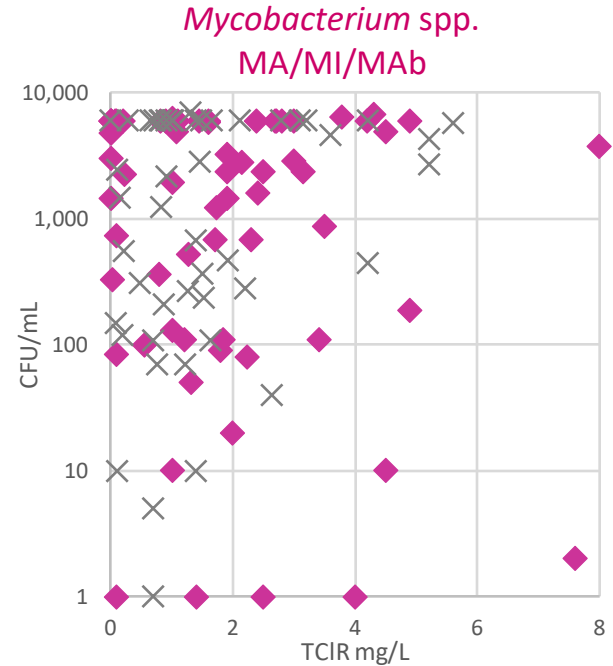
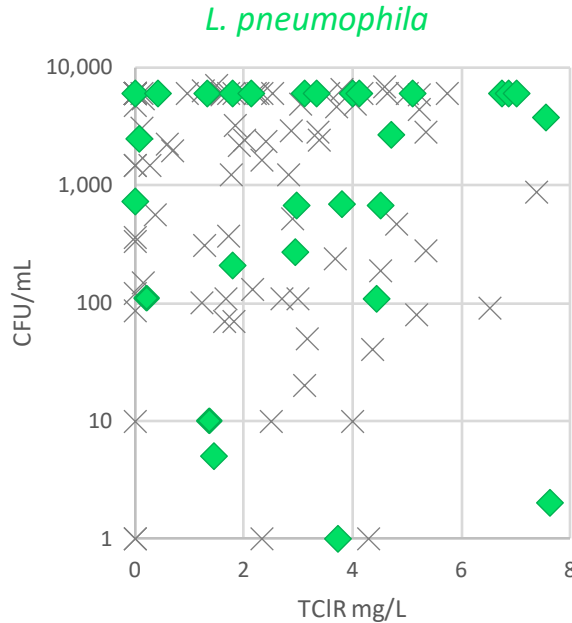
HPC Scale



Highest Concentration



Lowest Concentration

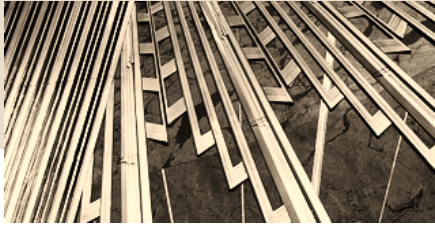
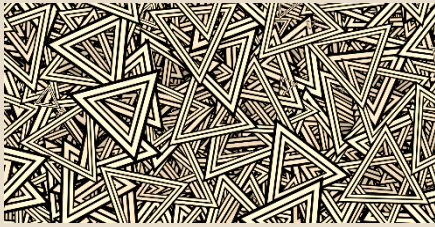


Lp/Myco positive Samples



Negative samples





Conclusions

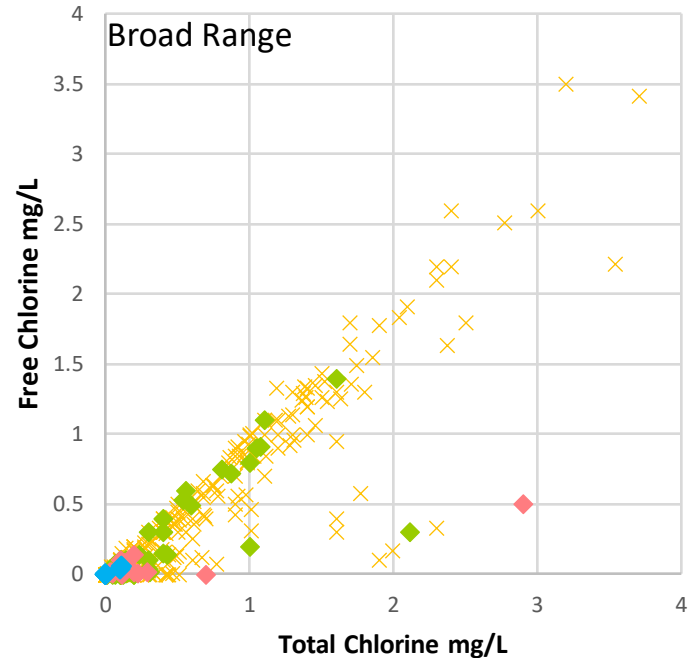
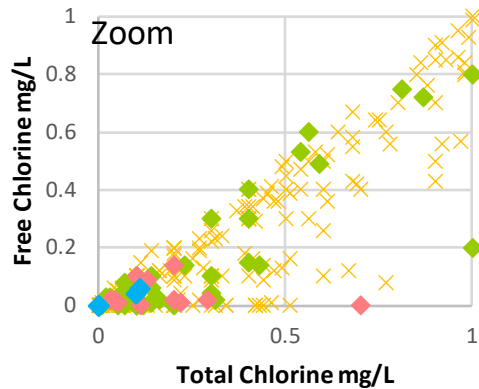
- Residual type (CI/CLM) does significantly influence occurrence patterns *M. avium* and *M. Abscessus*.
- Residual type (CI/CLM) does significantly influence concentration *L. pneumophila* and *M. intracellulare*.
- CLM is effective for controlling *L. pneumophila*, but not MA/MI/Mab.
- CL is relatively more effective at controlling MA/MI/Mab, than CLM.
- Temperature is a stimulant for microbial growth, but acts as a deterrent especially if a residual is maintained in the hot water.

Influence of Total and Free Chlorine on *L. pneumophila* Occurrence

qPCR Framework: Lee et al. 2011

- ◆ Action: (Concern) >4,000 GU/100mL/Typically Culture Positive
- ◆ Alert: (Concern) >400-4,000 GU/100mL
- ◆ Satisfactory: (Not of concern) 1-400 GU/100mL
- ✕ Samples **NOT** *L. pneumophila* positive

GU= Genomic Unit/Genomic Target

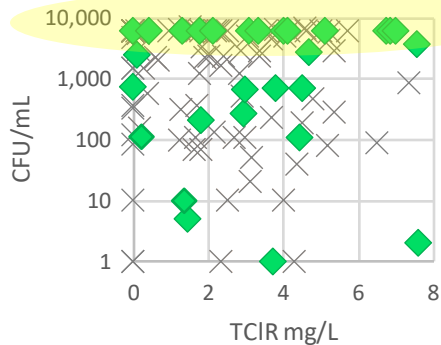


Influence of Monochloramine and Free Ammonia on *L. pneumophila* Occurrence

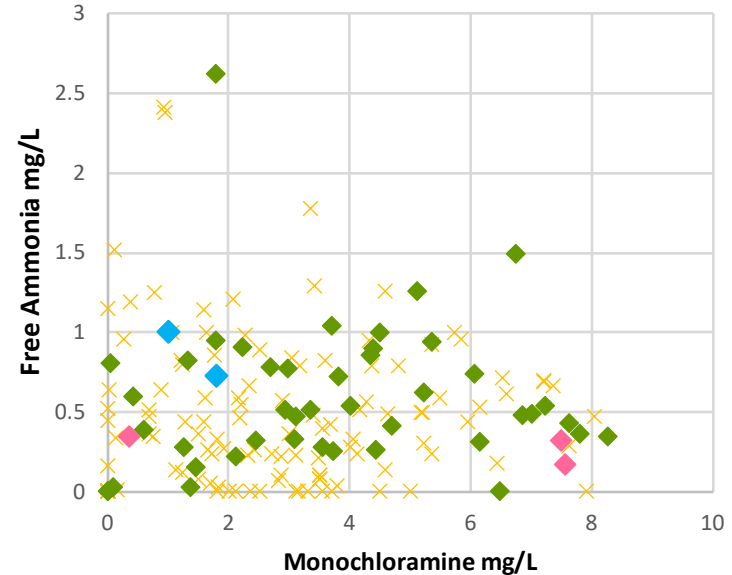
qPCR Framework: Lee et al. 2011

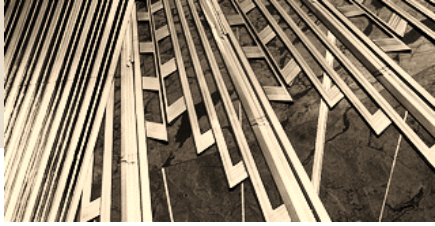
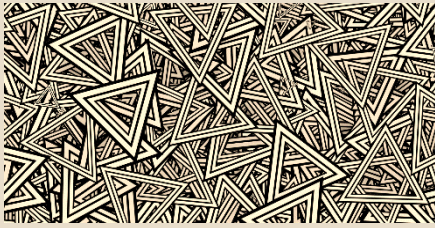
- ◆ Action: (Concern) >4,000 GU/100mL/Typically Culture Positive
- ◆ Alert: (Concern) >400-4,000 GU/100mL
- ◆ Satisfactory: (Not of concern) 1-400 GU/100mL
- ✕ Samples **NOT** *L. pneumophila* positive

HPC
Results



L. pneumophila Occurrence by
Monochloramine and Free Ammonia





In the Larger Context

- JUST because your system uses CLM. Does NOT mean your water has MA/MI/Mab issues.
- JUST because your system uses CL doesn't mean you have *L. pneumophila* issues.
- If you have *L. pneumophila* issues and you're on a CL system is most likely due to a lack of an active residual.
- A residual correction is not available for CLM systems.
- REMEMBER these observations are broad brush strokes which may or may not be applicable to your specific water system.
- Also REMEMBER, today I talked about just two water-borne bacteria and these observations do NOT take into account how other water pathogens will responds to our treatment and practices with water.

EPA RESEARCHERS

- Collaborators:
- Jatin Mistry
 - Dr. Stacy Pfaller
 - Dawn King
 - Dr. Steve Vesper

Applied and Environmental Microbiology

Chlorine and Monochloramine Disinfection of *Legionella pneumophila* Colonizing Copper and Polyvinyl Chloride Drinking Water Biofilms

Helen Y. Bao¹, Brian J. Morris¹, Ian T. Stouring¹, Jeffrey G. Szabo¹

¹U.S. Environmental Protection Agency, Office of Research and Development, National Homeland Security Research Center, Cincinnati, Ohio, USA

ABSTRACT Building water systems promote the growth and survival of opportunistic pathogens, such as *Legionella pneumophila*, especially within biofilms, where most drinking water microbes reside. However, compared to their planktonic form, disinfection efficacy for the biofilm-associated forms of water-based pathogens is unclear. The aim of this study was to determine the effectiveness of free chlorine and monochloramine in the inactivation of biofilm-associated *L. pneumophila* strain Philadelphia-1 serogroup 1 (Lp215). Mature (1.5- to 2-year-old) drinking water biofilms were developed on copper (Cu) and polyvinyl chloride (PVC) slides within biofilm anaerobic reactors then colonized with Lp215 at approximately 4 log₁₀ CFU cm⁻² and exposed to 2 mg liter⁻¹ of free chlorine or monochloramine. Cl₂ disinfection inactivated *L. pneumophila* more consistently with Lp215 at approximately 4 log₁₀ CFU cm⁻², and 4-log₁₀ reductions of planktonic and biofilms Lp215 were determined. For planktonic Lp215, free chlorine was more effective at inactivation than was monochloramine treatment, and for biofilm-associated Lp215, monochloramine was more effective on Cu biofilms while free chlorine was more effective on PVC biofilms. In contrast to monochloramine, free chlorine treatment of Cu and PVC biofilms, negatively impacted Lp215 16S rRNA gene transcript levels and may act synergistically with Cu surfaces to further reduce transcript levels. Moreover, Lp215 cells shed from biofilms into the bulk water were more resistant to disinfection than were planktonic Lp215 cells. Results from this study indicate that biofilm-associated, disinfection type, and substratum play an important role in the survival of *L. pneumophila* serogroup 1 biofilms within water systems.

IMPORTANCE Microbial regrowth within building water systems are promoted by low stagnation, low disinfectant residual, high surface-to-volume ratio, amenable growth temperatures, and colonization of drinking water biofilms. Moreover, biofilms provide protection from environmental stresses, access to higher levels of nutrients, and opportunities for symbiotic interactions with other microbes. Disinfection efficacy information is historically based on inactivation of pathogens in their planktonic, free-floating forms. However, due to the ecological responses of drinking water biofilms for pathogen survival, this study evaluated the efficacy of two common disinfectants, free chlorine and monochloramine, on *Legionella pneumophila* colonizing mature, drinking water biofilms established on copper and PVC surfaces. Results showed that inactivation was dependent on the disinfectant type and biofilm substratum. Overall, this and other related research, will provide a better understanding of *Legionella* ecological stability and survival and all policy makers in the management of exposure risks to water-based pathogens within building water systems.

KEYWORDS PVC biofilms, disinfection, drinking water distribution system, opportunistic pathogens, premise plumbing

April 2016, Volume 82, Issue 7, e00616-16 Applied and Environmental Microbiology

Downloaded from http://aem.asm.org/ on January 14, 2020 at US EPA Environmental Library

Electrolyte mobility of *Legionella pneumophila* serogroup 1 to 14

Wenke Y. Sun^{1,2}, M. K. Becker¹, Cheryl Muehlen¹ and Darren A. Lippel¹

¹U.S. Environmental Protection Agency, Office of Research and Development, National Homeland Security Research Center, Cincinnati, Ohio, USA; ²Department of Environmental and Ecological Engineering, University of Cincinnati, Cincinnati, Ohio, USA

ABSTRACT The electrostatic forces between the cell surface and the surrounding water molecules are important for the stability of the cell membrane and the cell's ability to maintain its internal environment. The electrostatic forces between the cell surface and the surrounding water molecules are important for the stability of the cell membrane and the cell's ability to maintain its internal environment.

J. Clin. Tuberc. Other Mycobact. Dis.

Application of diagnostic criteria for non-tuberculous mycobacterial disease to a case series of respiratory patient isolates

Amara A. Chohan¹, Caren A. Janda¹, Megan Anderson¹, Amy M. Hahn¹, Christopher A. Johnson¹, Joseph J. Tenover¹, and Joseph B. Tenover¹

ABSTRACT Non-tuberculous mycobacteria (NTM) are a diverse group of bacteria that can cause a variety of clinical syndromes. The purpose of this study was to evaluate the utility of diagnostic criteria for NTM disease in a case series of respiratory patient isolates.

EPA Public Access

Electrolyte mobility across membrane point-of-use filters for effective separation and in situ inactivation of *Legionella pneumophila*

Abstract: The electrostatic forces between the cell surface and the surrounding water molecules are important for the stability of the cell membrane and the cell's ability to maintain its internal environment.

EPA Public Access

Efficacy of inactivation of human enteroviruses by tri-oxymethylene generated ultraviolet light emitting diodes (LED)

Abstract: The purpose of this study was to evaluate the efficacy of inactivation of human enteroviruses by tri-oxymethylene generated ultraviolet light emitting diodes (LED).

Water Research

Removing arsenic and co-occurring contaminants from drinking water by full-scale ion exchange and point-of-use/point-of-entry reverse osmosis systems

Abstract: This study investigated the performance of two full-scale ion exchange (IX) systems, one point-of-entry (POE) reverse osmosis (RO) system and one point-of-use (POU) RO system for simultaneous removal of arsenic and removal of co-occurring contaminants from drinking water. The study was performed as part of the U.S. Environmental Protection Agency's Arsenic Treatment Evaluation Program (ATEP). The IX system with strong base anion (SBA) resin, effectively removed arsenic (As), lead (Pb), and cadmium (Cd) to below respective maximum contaminant levels and secondary MCLs and installed between the POE and POU. The POE RO system with reverse osmosis membrane (ROM) in water mains, the POE of dual resin - an anion SBA resin and a polyethylene SBA resin - effectively removed As and allowed the system to perform at a level level through for 12 months under Arsenic and nitrate loading scenarios when the resin was re-regenerated. The removal of contaminants appeared to follow a selectivity sequence: (As) > (Pb) > (Cd) > (NO₃) > (NO₂). Microbially reduced arsenic, nitrate, nitrite, nitrate, and cadmium, results with a 20% reduction rate. The POE RO system with dual plating (only nitrate) at a level of 10 mg/L and the POE RO system with dual plating (only nitrate) at a level of 10 mg/L and the POE RO system with dual plating (only nitrate) at a level of 10 mg/L.

Microbiology

Draft Genome Sequences of Seven *Legionella pneumophila* Isolates from a Hot Water System of a Large Building

Abstract: The purpose of this study was to determine the genetic relatedness of seven *Legionella pneumophila* isolates from a hot water system of a large building.

1. Introduction

Arsenic (As) exposure has long been linked to bladder, lung, and skin cancers, and more recent science shows that it can also increase risks of cardiovascular, developmental, and birth problems (1). The U.S. Environmental Protection Agency (EPA) lowered the maximum contaminant level (MCL) for arsenic in drinking water from 50 to 10 µg/L in January 2002 (1)(2). Since then, the driver has continued to prompt concerns the health effects of its exposure at levels <10 µg/L (such as Mistry et al., 2010; Kim et al., 2012; National Institute of Health, 2013). Currently, the EPA's Integrated Risk Information System Program is updating its P888 health hazard assessment of inorganic arsenic (from which the 10 µg/L MCL was based) to support EPA's regulatory activities and decisions to protect public health (1)(3, 2013). In July 2009, New Hampshire became the second state in the US, after New Jersey, to set a more stringent arsenic drinking water standard of 5 µg/L, half of the Federal MCL (New Hampshire Public Health, 2010).

Arsenic levels in the US tend to be higher in groundwater supplying rural small communities, most of which install treatment systems to meet the federal and state arsenic standards. These small systems continue to seek innovative, cost-effective treatment technologies, especially those proven with scale, long-term performance data (1)(Kim et al., 2012). A wealth of

Thank You!



Q&A Session

We highly value your feedback.

Please take a few minutes to complete our survey
at your convenience:

surveymonkey.com/r/EPASmallSystems