Assessing Distribution System Integrity:

the case for maintaining a disinfectant residual

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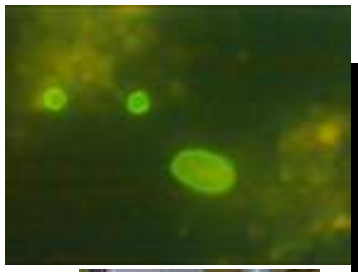
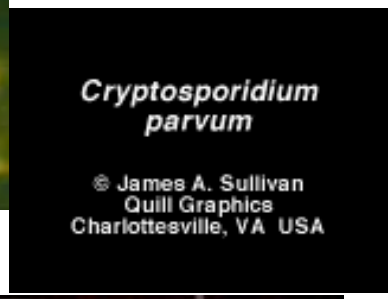
Regulation of Disinfection in the US

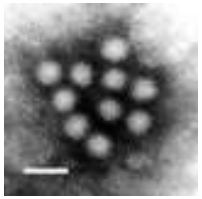
- **Surface Water Treatment Rule**
  - Giardia and Virus CT values
  - Maintenance of disinfectant residual at 95% locations
- **Long Term II Enhanced Surface Water Treatment Rule**
  - Cryptosporidium
- **Groundwater Rule**
  - Viruses
- **Stage 1 Disinfection/Disinfection By-Product Rule**
  - maximum residual limit (based on an annual average) of 4 mg/L for free chlorine and chloramines
- **Total Coliform Rule**
  - Disinfectant residual monitoring locations

Water Treatment: the Multiple Barrier Concept

- **Source Water Protection**
  - Surface Water
  - Groundwater
- **Filtration**
- **Disinfection**
- **Distribution System**
  - Chlorine residual
  - Pressurized networks
  - Cross connection control







Dead-End Free Chlorine Residual

Residual mg/L	N	#Samples	# Positive	# Colonies	% Positive	Avg/100 mL
0 - 0.2	99	11,056	138	10,535	1.248	0.953
0.2 - 0.5	159	10,637	36	2,850	0.338	0.267
0.5 - 1.0	164	14,276	87	2,107	0.609	0.147
> 1.0	127	7,803	118	4,955	1.512	0.635

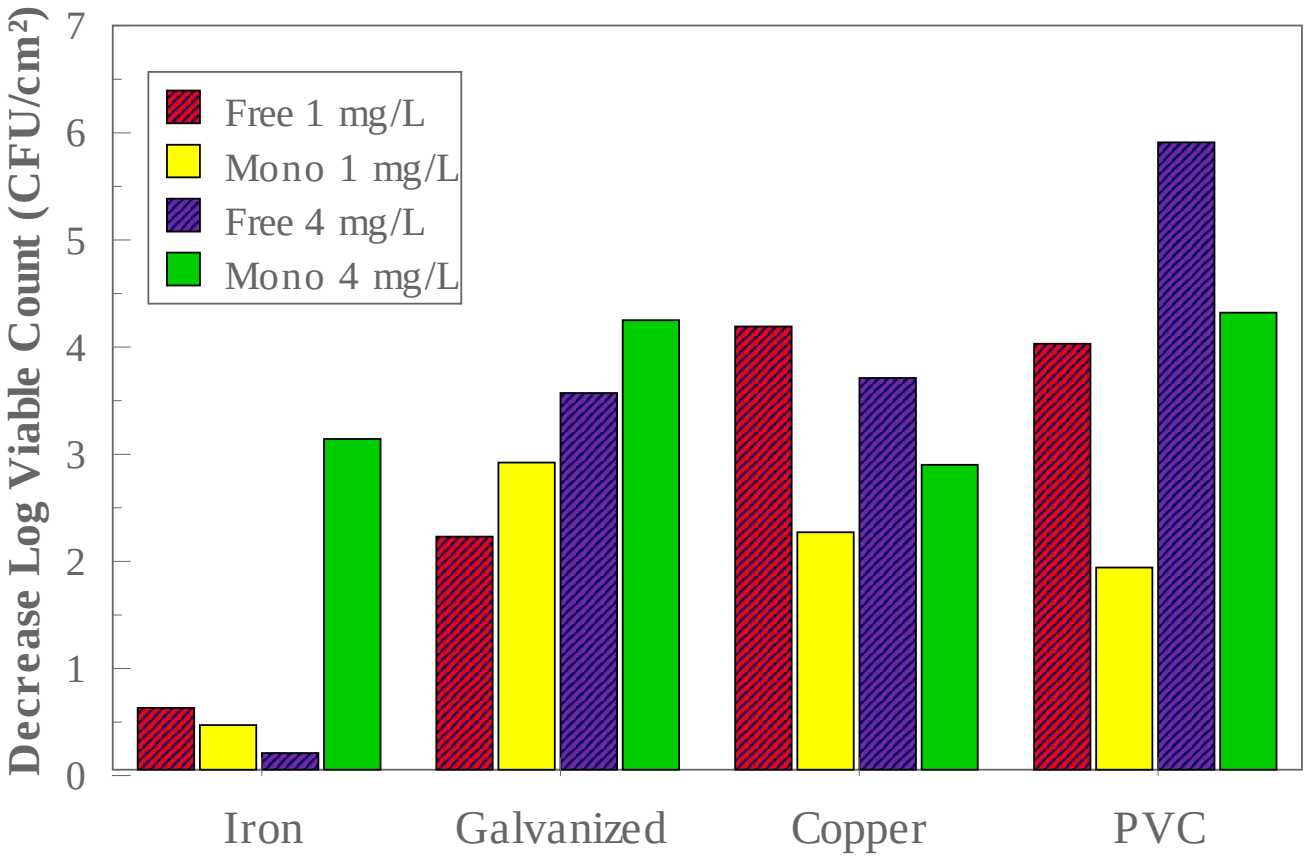
LeChevallier et al., 1996. *Appl. Environ. Microbiol.* 62(7): 2201-2211.

Dead-End Chloramine Residual

Residual mg/L	N	#Samples	# Positive	# Colonies	% Positive	Avg/100 mL
0 - 0.5	110	11,447	67	331	0.585	0.029
0.5 - 1.0	125	7,106	20	66	0.281	0.009
1.0 - 2.0	121	7,564	13	15	0.171	0.001
> 2.0	105	9,835	83	213	0.844	0.022

LeChevallier et al., 1996. *Appl. Environ. Microbiol.* 62(7): 2201-2211.

Impact of Pipe Surface on Disinfection of Biofilm Bacteria

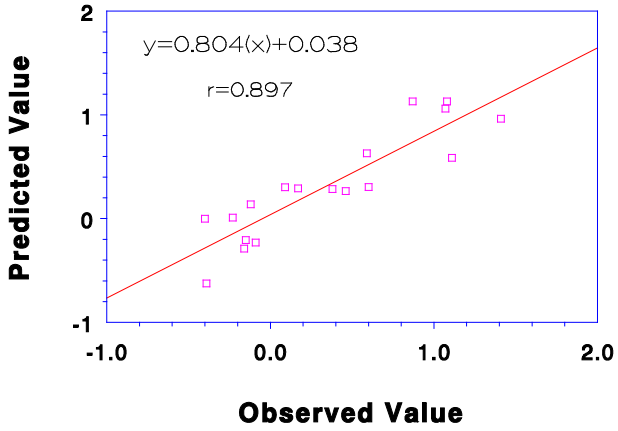


LeChevallier, Lowry, and Lee. 1990. *J. Amer. Water Works Assoc.* 82(7): 87-99.

Model for Monochloramine Disinfection of Biofilm Bacteria

	Coefficient	Standard Error	*t*-Statistic	Significance Level
Log reduction viable counts=				
Intercept	-1.0734	0.5685	-1.888	0.0816
Log Larson Index	-0.5808	0.l963	-2.958	0.0111
Log Corrosion Rate	-0.4820	0.3205	-1.504	0.1566
Log Monochloramine	2.0086	0.9226	2.177	0.0485
Phosphate Level	0.1445	0.0336	4.295	0.0009
Corrected R-Squared:	0.746	F test:	13.474	

Model is based on 18 observations



LeChevallier, Lowry, and Lee. 1990. *J. Amer. Water Works Assoc.* 82(7): 87-99.

Nosocomial Legionnaires' Disease

Kool *et al*., *Lancet* 353: 272-277 1999

- Examined 32 nosocomial outbreaks, 1979-1997, in which drinking water was implicated
  - Examined characteristics of the hospital (size, transplant program), primary disinfectant treatment, disinfectant residual, water source, community size, pH.
- Odds of nosocomial outbreak was 10.2 (1.4-460) higher in systems that maintained free chlorine versus a chloramine residual.
- Estimated that 90% of outbreaks could be prevented if chloramines were universally sed.

Nosocomial Legionnaires' Disease

International Conference on Nosocomial Infections (www.decennial.org):

- ✓ Survey 166 hospitals. Those supplied with chloraminated water were less likely (RR=0.36, CI=0.18-0.72) to have nosocomial Legionnaires disease.

International Legionella Conference (www.uni-ulm.de):

- ✓ Monochloramine at 1.5 mg/L resulted in >99.9% inactivation of Legionella biofilms within 60 min.

Association for Professionals in Infectious Control (www.apic.org):

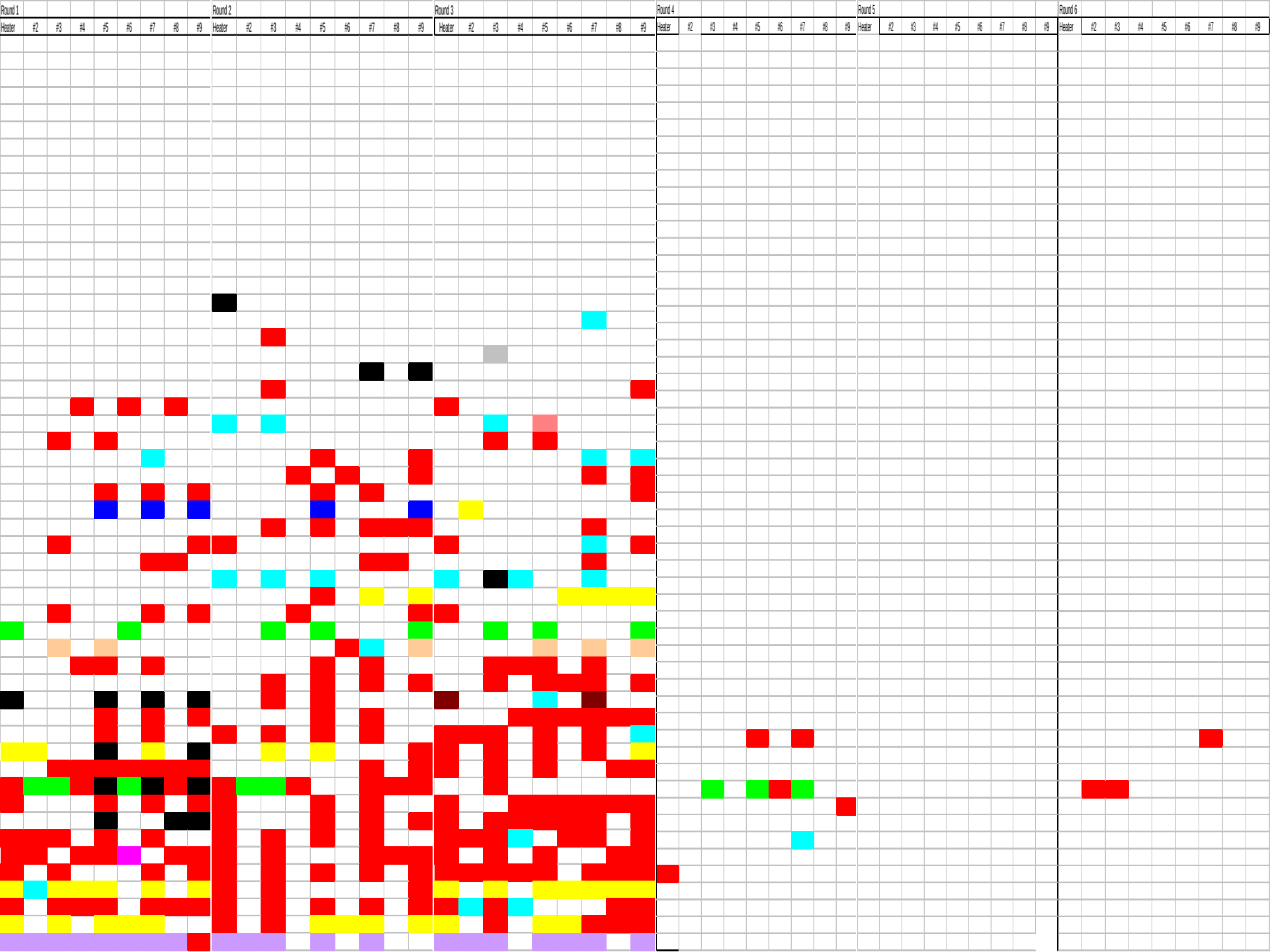
- ✓ Fed chloramines to a hospital. Legionella were 97.9 cfu/mL before (n=72), and 0.13 cfu/mL after (n=104) treatment with 0.1 mg/L chloramines.

Lessons from Real Life:
San Francisco, CA

- **53 buildings**
- **Sampled 3 times pre- and post-conversion to chloramines**
- **Sampled hot water heater and four distal sites**
- **Sampled swab and water from distal sites**
- **Surveys collected data on building age, height, type and number of hot water heaters**
- **pH, temperature, free or total Cl_2 residual measured for each sample**

Flannery, B. et al. 2006. Reducing *Legionella* colonization of water systems with monochloramine. Emerg. Infect. Dis. 12(4): 588-596.

http://www.cdc.gov/ncidod/EID/vol12no04/05-1101.htm.


Round 1
Heater
#2
#3
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#5
#6
#7
#8
#9
Round 2
Heater
#2
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#6
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#9
Round 3
Heater
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Round 4
Heater
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Round 5
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Round 6
Heater
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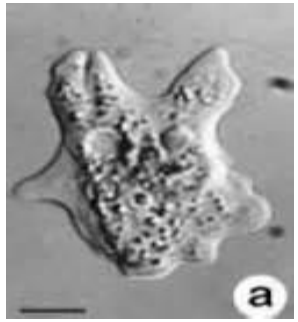
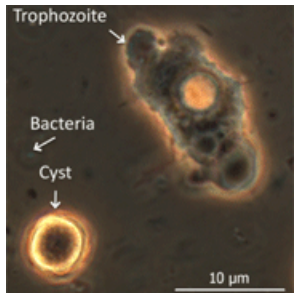
Legionella and Amoebae

- Intracellular *Legionella* in: *Acanthamoeba, Amoeba, Comandonia, Echinamoeba, Filamoeba, Hartmannella, Naegleria, Paratetramitus, Vahlkamfia, Tetrahymena, Dictyostelium*
- *Legionella* survive for months, resistant to 50 mg/L free chlorine for 18 hr
- Coated with amoebal proteins
- Increases virulence, replication
- *Legionella*-containing vacuoles expelled prior to encystation
- Trophozoite stage sensitive to disinfectants ($CT_{99.9}$ = 1.5 mg-min/L)

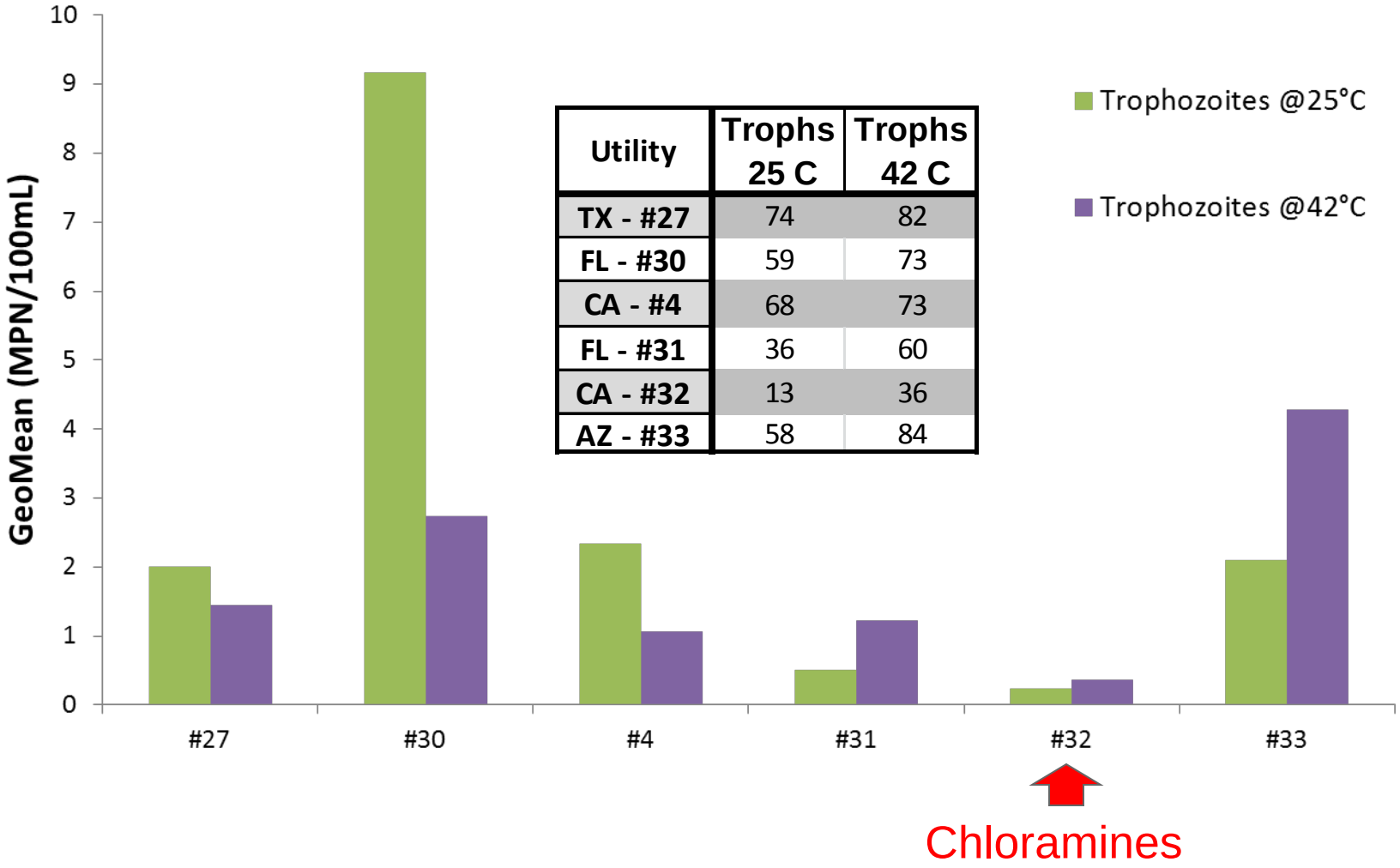


Trophozoite


Cyst



Trophozoite Concentration



Utility	Trophs 25 C	Trophs 42 C
TX - #27	74	82
FL - #30	59	73
CA - #4	68	73
FL - #31	36	60
CA - #32	13	36
AZ - #33	58	84

Disinfectant Residual Performance Assessment

Performance Goals:

- **Chlorine residual 95% > 0.2mg/L free chlorine or > 0.5 mg/L total chlorine (chloramine systems)**
- **Chlorine residual may not be undetectable for two consecutive months**
- **Monitoring based on a representative system wide plan consisting of key sites and compliance sites:**
  - Stage 1 & 2 DBP sites, TCR and tank sites and all pressure zones
  - The minimum number of sites should be population based
  - Monthly minimum monitoring
  - Sample taps flushed to be representative of water in the main
  - Testing conducted using colorimeter or online monitor

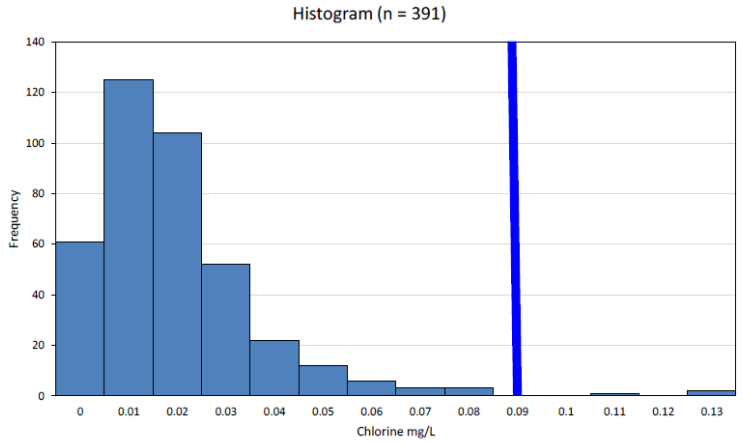
Friedman, M., G. Kirmeyer, J. Lemieux, M. LeChevallier, S. Seidl, and J. Routt. 2010. Criteria for Optimized Distribution Systems. Water Research Foundation, Denver, CO.

State	Minimum Distribution System Residual (mg/L)
Alabama	0.2 (free)
California	0.2 (free)
Delaware	0.3 (free)
Florida	0.2 (free), 0.6 (total)
Georgia	0.2 (free)
Illinois	0.3 (free), 0.5 (total)
Indiana	0.2 (free), 0.5 (total)
Iowa	0.3 (free), 1.5 (total)
Kansas	0.2 (free), 1.0 (total)
Kentucky	0.2 (free), 0.5 (total)

State	Minimum Distribution System Residual (mg/L)
Louisiana	0.5 (free or total)
Missouri	0.2 (total)
Nebraska	0.2 (free), 0.5 (total)
North Carolina	0.2 (free), 1.0 (total)
Ohio	0.2 (free), 1.0 (total)
Oklahoma	0.2 (free), 1.0 (total)
Tennessee	0.2 (free)
Texas	0.2 (free), 0.5 (total)
West Virginia	0.2 (total)

Accuracy of Disinfectant Residual Measurement

- Important to consider measurement variation
- If the true target is 0.2 mg/L, and measurements have 0. mg/L variation, then utilities must maintain 0.3 mg/L to ensure compliance



- Most systems will utilize an 80% safety factor
- Therefore systems will target 0.4-0.5 mg/L for compliance