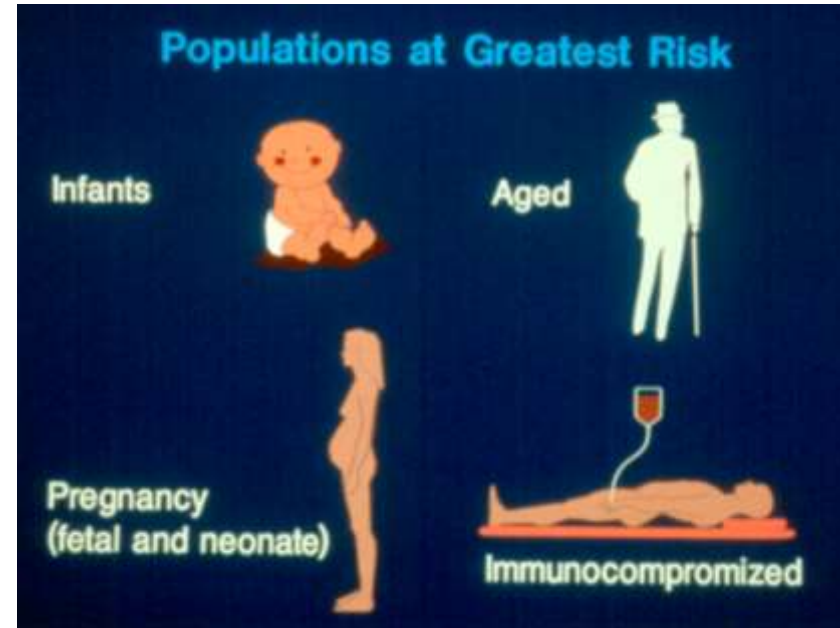


Legionella and the revolution in water distribution microbiology

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Water Quality Impacts Health



The Issues:

- Aging infrastructure: New materials removing lead, preventing leaking, reducing water retention times.
- Source water change: New water source (desalination, reuse); pollution of current source, climate impacts; overall water quality change (toxic algae)
- Emerging/ Re-emerging hazards (chemical and biological) includes *Legionella*. Chronic outcomes!
- Disinfection: moving disinfection from an art to a science (inactivation studies, sensors, stability)
- Social Structures: Changes in vulnerable and sensitive populations, changes in community structure (access to wholesome food; access to education).

FEBRUARY 3, 2015

TIME

The Poisoning Of An American City



Toxic water. Sick kids.
And the incompetent
leaders who betrayed Flint

By Josh Sanburn

time.com

What is the role of public health and the role of the water industry in understanding risks associated with distribution system water quality problems?



Flint Michigan

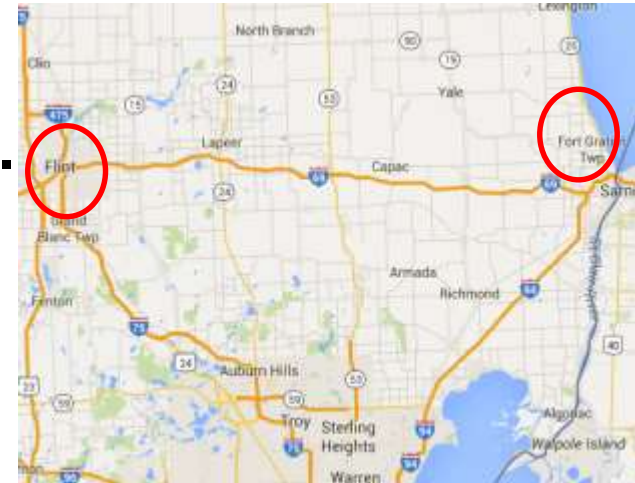


- Population in Flint peaked in 1960 at ~200,000
- Population now <100,000. Water usage is down by 2/3, so water spends much more time in system than is conventional
- Vulnerable, low-income residents
- Many older houses have lead services lines and/or plumbing (estimated at 15,000)
- Some distribution mains are thought to be lead

Slide provided by Dr. Susan Masten
Environmental Engineering
Michigan State University

Background

- The Flint plant was completed in 1954.
- Flint has purchased water from Detroit Water and Sewage Department (DWSD) since 1967.
- The source of the DWSD water is Lake Huron and treated at the Fort Gratiot plant.



Slide provided by Dr. Susan Masten
Environmental Engineering
Michigan State University



Timeline



- **March 31, 2014** Flint plant supervisor, Brent Wright, signs permit application for sludge lagoon upgrades. Application is submitted to DEQ for review and approval
- **April 9, 2014** MDEQ approves permit
- **April 25, 2014** Flint River changeover ceremony
- **April 30, 2014** DWSD Water line closed

Slide provided by Dr. Susan Masten
Environmental Engineering
Michigan State University

Timeline

- **June 2014** Complaints regarding water quality begin (smell, taste, discoloration)
- **August 14, 2014** Flint water tests positive for E coli. Boil water advisories issued two days later. Problems continue with three boil water advisory notices issued in a 22-day span in summer
- **Summer 2014** 29 cases of Legionellosis
- **October 13, 2014** GM engine plant announces that it will stop using Flint water



www.Flintwaterstudy.org



Steve Carmody/Michigan Radio

Slide provided by Dr. Susan Masten
Environmental Engineering
Michigan State University

Timeline

- **November 2, 2014** City increases hydrant flushing to address red water concerns
- **December 16, 2014** City receives official violation notice from DEQ for violations of the Safe Drinking Water Act for total trihalomethanes



Photo courtesy of: Erin Brochovitch

Timeline

- **February 2015:** City of Flint tests water of Lee Ann Walters and finds 104 ppb and 397 ppb. Iron level > 3.3 mg/L (> LOQ)
 - Water was filtered at the home
 - Sampling done after flushing
 - Internal plumbing found to be plastic, a portion external service line found to be galvanized iron pipe; the rest was lead
- **February 25, 2015:** Lee Ann Walters contacts Region 5 EPA regarding her concerns over lead levels in her water. Miguel del Toral calls the results alarming

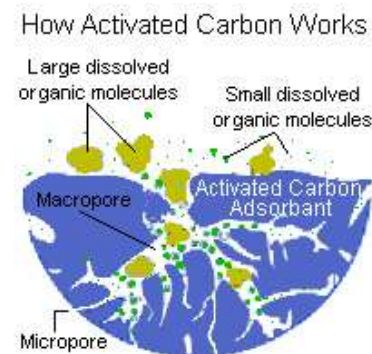


<http://www.sereco.it/prodotti.php?vedi=20120167>

Timeline

Slide provided by Dr. Susan Masten
Environmental Engineering
Michigan State University

- **May 2015** More *Legionella* cases
- **June 2015** Second violation of D/DBP Rule
- **Late July 2015** Flint installs a granular activated carbon filter to control THMs by removing organic matter



<http://cyber-nook.com>

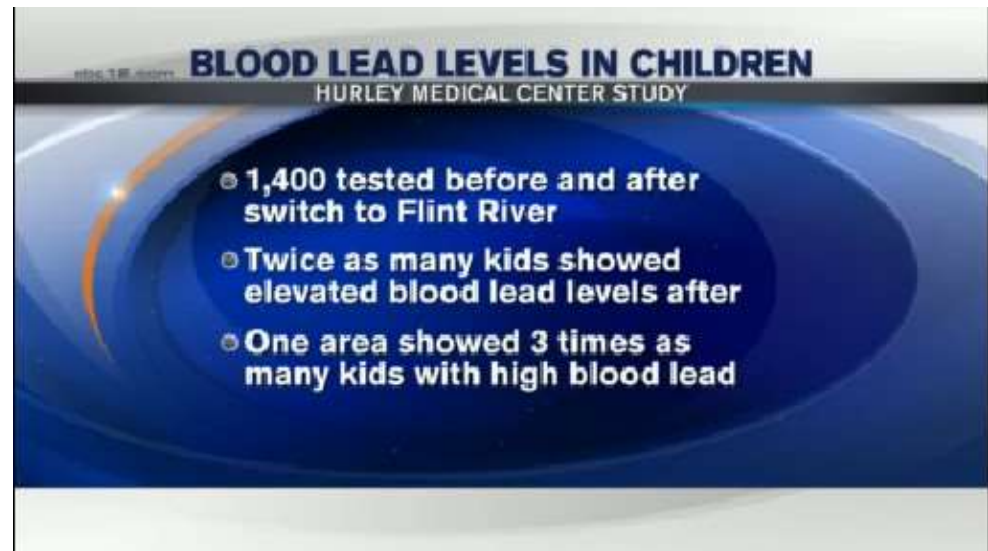
Timeline

- **August 31, 2015** Prof. Marc Edwards, VA Tech says Flint drinking water is "very corrosive" and "causing lead contamination in homes"
 - 20% of the 120 samples exceeded the U.S. EPA lead action level of 15 ppb
 - 42% of the 120 samples had lead levels that were >5 parts per billion, "which suggests a serious lead-in-water problem" according to Prof. Edwards

Timeline

- **September 24, 2015** Dr. Mona Hanna-Attisha releases study showing that the number of Flint infants and children with elevated blood lead levels have increased since the switch to Flint River Water

Slide provided by Dr. Susan Masten
Environmental Engineering
Michigan State University



Timeline

- **October 16, 2015** Flint switches back to “Detroit” water which comes from Lake Huron
- **December 9, 2015** Flint starts adding additional phosphate to increase the concentration from 1 to 2.5 mg/L for corrosion control



<http://flintwaterstudy.org/page/2/>

Slide provided by Dr. Susan Masten
Environmental Engineering
Michigan State University

E.coli, TTHMs, Lead, *Legionella*

Problems for premise plumbing and distribution systems

E. coli Zero allowed in tap water: a measure of water quality fecal pollution, presence indicates the possible presence of pathogens. **If present must issue a boil order.**

Total trihalomethanes: a by product of chlorine disinfection, carcinogen, quarterly running average **if in violation must issue a public warning.**

LEAD

<http://www.who.int/mediacentre/factsheets/fs379/en/>

- Lead is a cumulative toxicant that affects multiple body systems and is particularly harmful to young children.
 - Childhood lead exposure is estimated to contribute to about 600 000 new cases of children developing intellectual disabilities every year.
 - Lead exposure is estimated to account for 143 000 deaths per year with the highest burden in developing regions.
 - Lead in the body is distributed to the brain, liver, kidney and bones. It is stored in the teeth and bones, where it accumulates over time. Human exposure is usually assessed through the measurement of lead in blood.
 - **There is no known level of lead exposure that is considered safe.**
 - Low level exposures have been shown to affect IQ, ability to pay attention, and academic achievement.
 - cannot be corrected.
 - Exposure to high levels of *lead* may cause anemia, weakness, and kidney and brain damage. Very high *lead* exposure can cause death.
- **EPA only has an action level of 15 ppb, must use corrosion control and need to remove lead pipes and lead soldering**

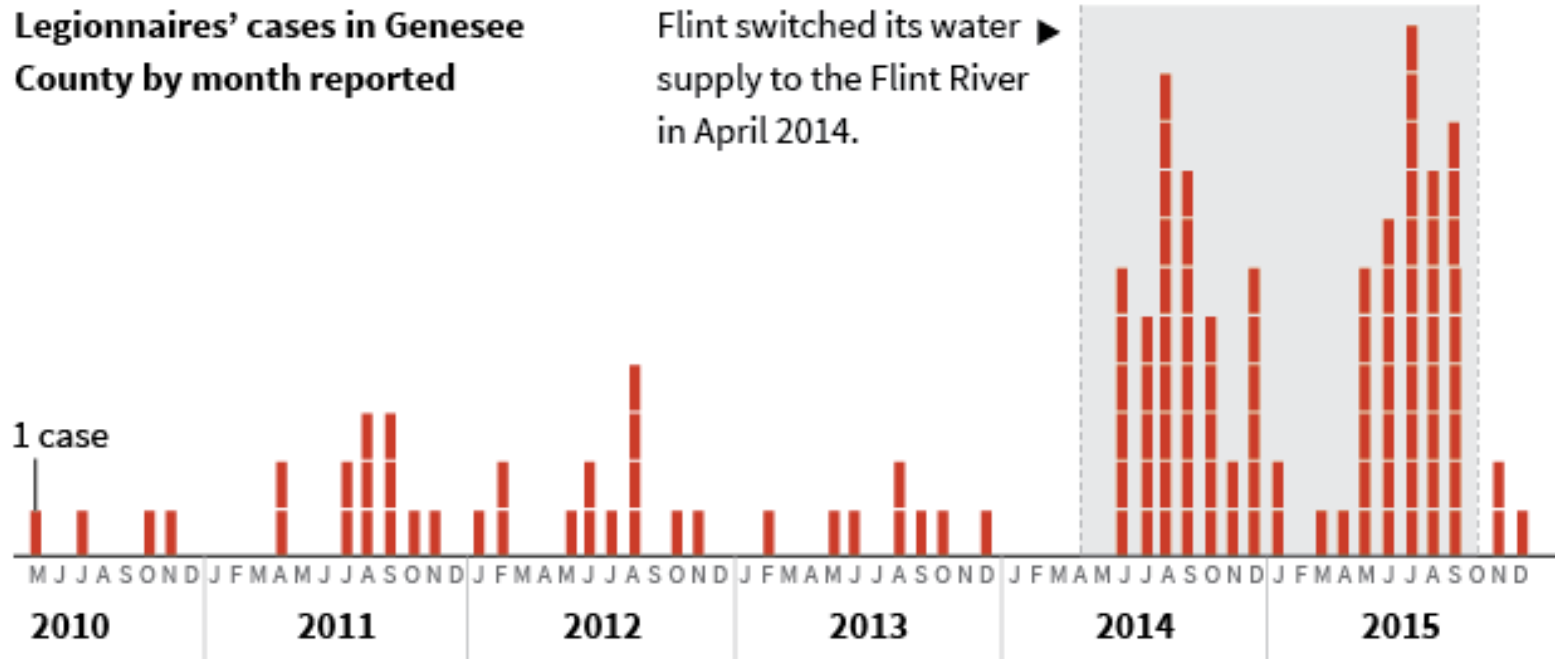
Legionnaire' Disease: 87 cases, 10 deaths

No official link has yet been detected between the city's water supply switching to the Flint River and the uptick in cases, but dozens have been sickened since April 2014.

City's water supply was switched back to Lake Huron.

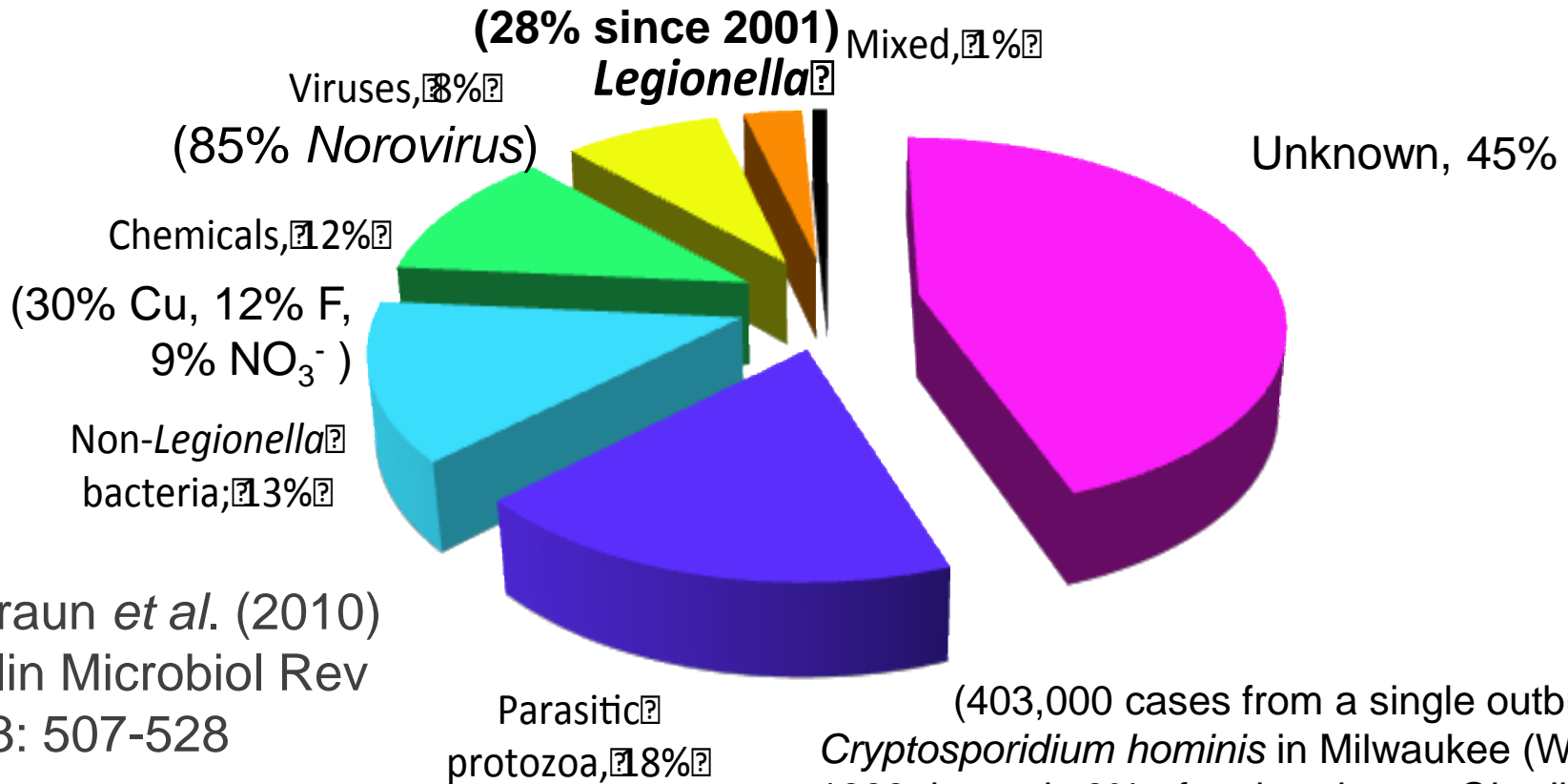
Legionnaires' cases in Genesee County by month reported

Flint switched its water supply to the Flint River in April 2014.



Note: Monthly case values are approximated for May/June 2015 and August/September 2015.

Disease agents from 780 drinking water outbreaks, 1971-2006 USA

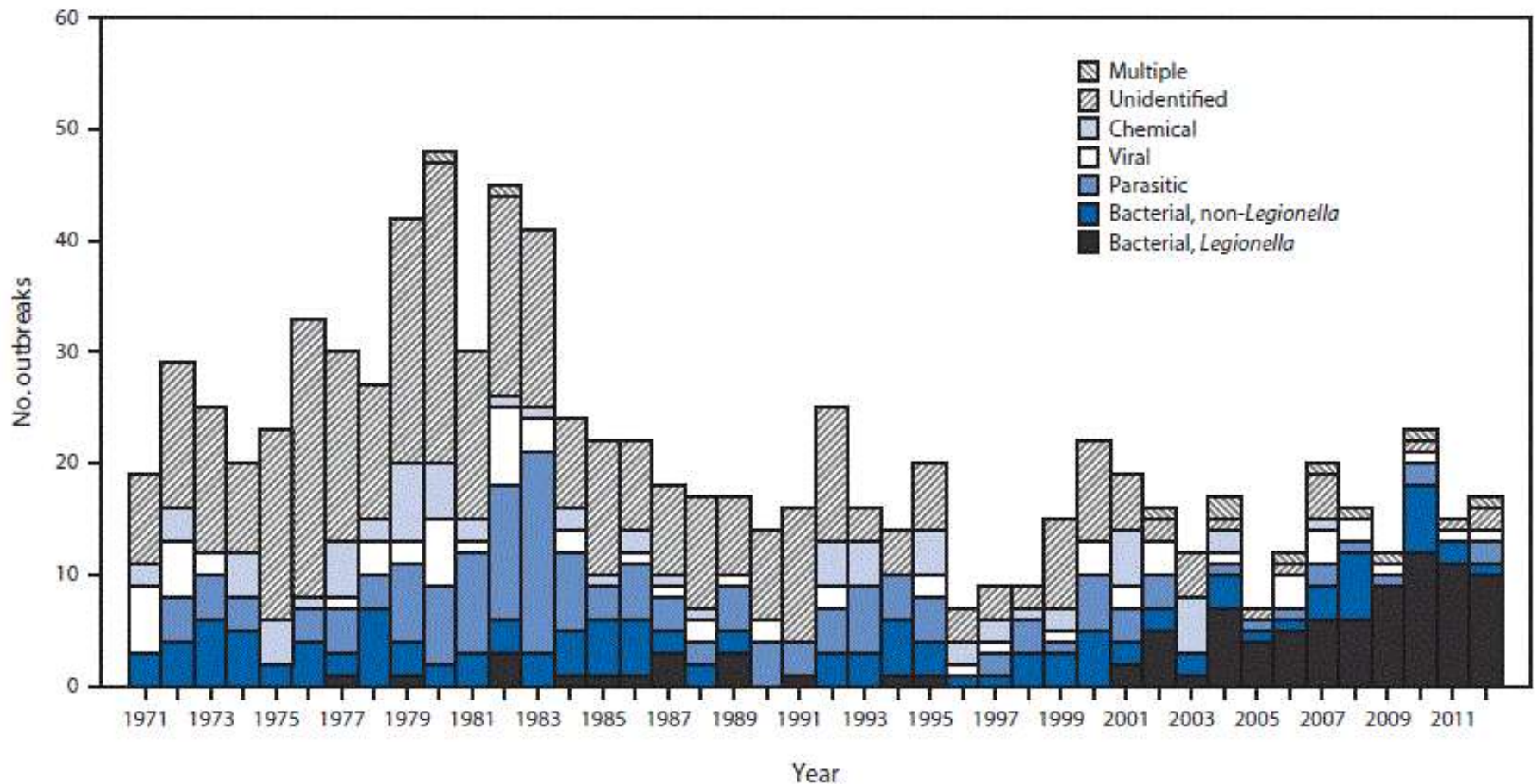


Craun *et al.* (2010)
Clin Microbiol Rev
23: 507-528

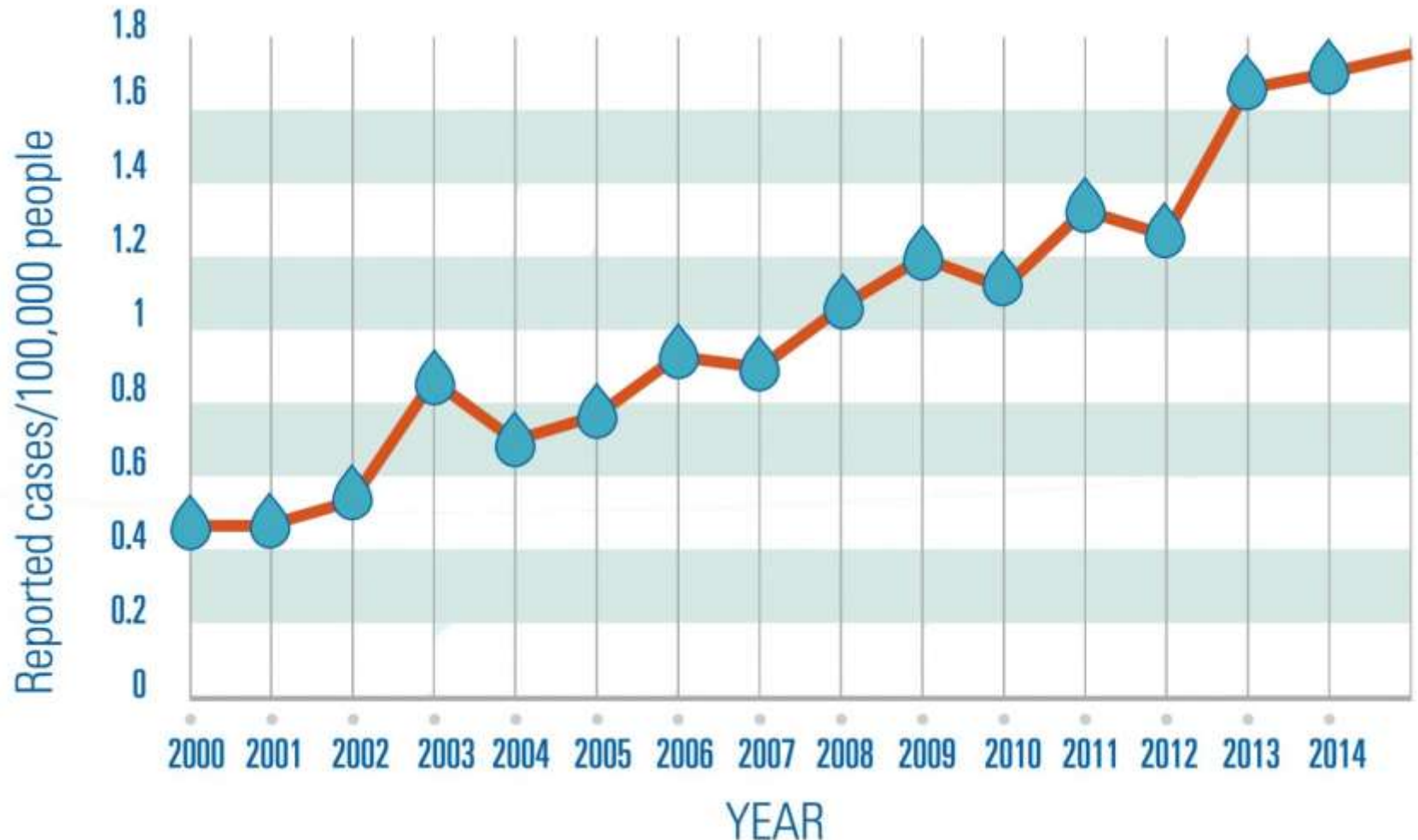
FIGURE. Etiology of 885 drinking water–associated outbreaks, by year — United States, 1971–2012*

MMWR:

<http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6431a2.htm>



The CDC analyzed outbreaks it had investigated from 2000 to 2014 that involved 415 cases, including 65 deaths. Most of the outbreaks were in buildings with large or complex water systems, such as hotels, hospitals and long-term-care facilities.



Legionnaire' Disease:

- New York Bronx July and Aug. 2015: 128 cases 12 deaths (cooling towers); Sept. 2015: 13 cases, 1 death.
- Every year, there are about 200 to 300 cases of Legionnaires' disease in New York City
- Milwaukee, July 2013, 27 cases
- Toronto, 2013: five times as many legionnaires' cases in a six-week period that summer compared to the last year (43 cases)
- Quebec, July 2012: 180 people were infected 13 people died. Office building suspected
- Chicago, 2012: 3 deaths, Hotel suspected

Public health hospitalization costs associated with US drinking water*

- CDC estimate drinking water disease costs > \$970 m/y
 - Less so faecal pathogens, largely Legionnaires' disease, *otitis externa*, and non-tuberculous mycobacterial (NTM) giving >40 000 hospitalizations/y

Disease	Annual costs
Cryptosporidiosis	\$46M
Giardiasis	\$34M
Legionnaires' disease	\$434M
NTM infection/Pulmonary	\$426M/ \$195M

*Collier *et al.* (2012) Epi Inf 140(11): 2003-13

Legionella

- Gram-negative
- Respiratory pathogen
 - Inhale droplets/particles containing bacteria
 - Alveoli – invade macrophage & reproduce
- Immunocompromised or immunosuppressed
 - >50 years
 - Smokers
 - Chronic lung disease
- Community-acquired Pneumonia
- 25 of 54 species cause human disease
 - *L. pneumophila*



Legionella Transmission is by Aerosol Inhalation from the water also potentially aspiration

-no person to person transmission

No EPA standard or rule to control *Legionella*

Legionnaires' Disease Pneumonia-Like

Symptoms

Cough

Muscle aches

High fever

Shortness of breath

Headache

ELDERLY those with chronic lung problems,
smokers more susceptible.

Pontiac Fever: an acute, nonfatal respiratory
disease causes a mild upper respiratory infection
that resembles acute influenza. Pontiac fever
resolves spontaneously and often goes
undiagnosed.

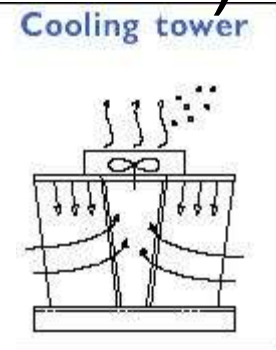


Sources of *Legionella*

<http://www.cdc.gov/legionella/downloads/fs-legionnaires.pdf>

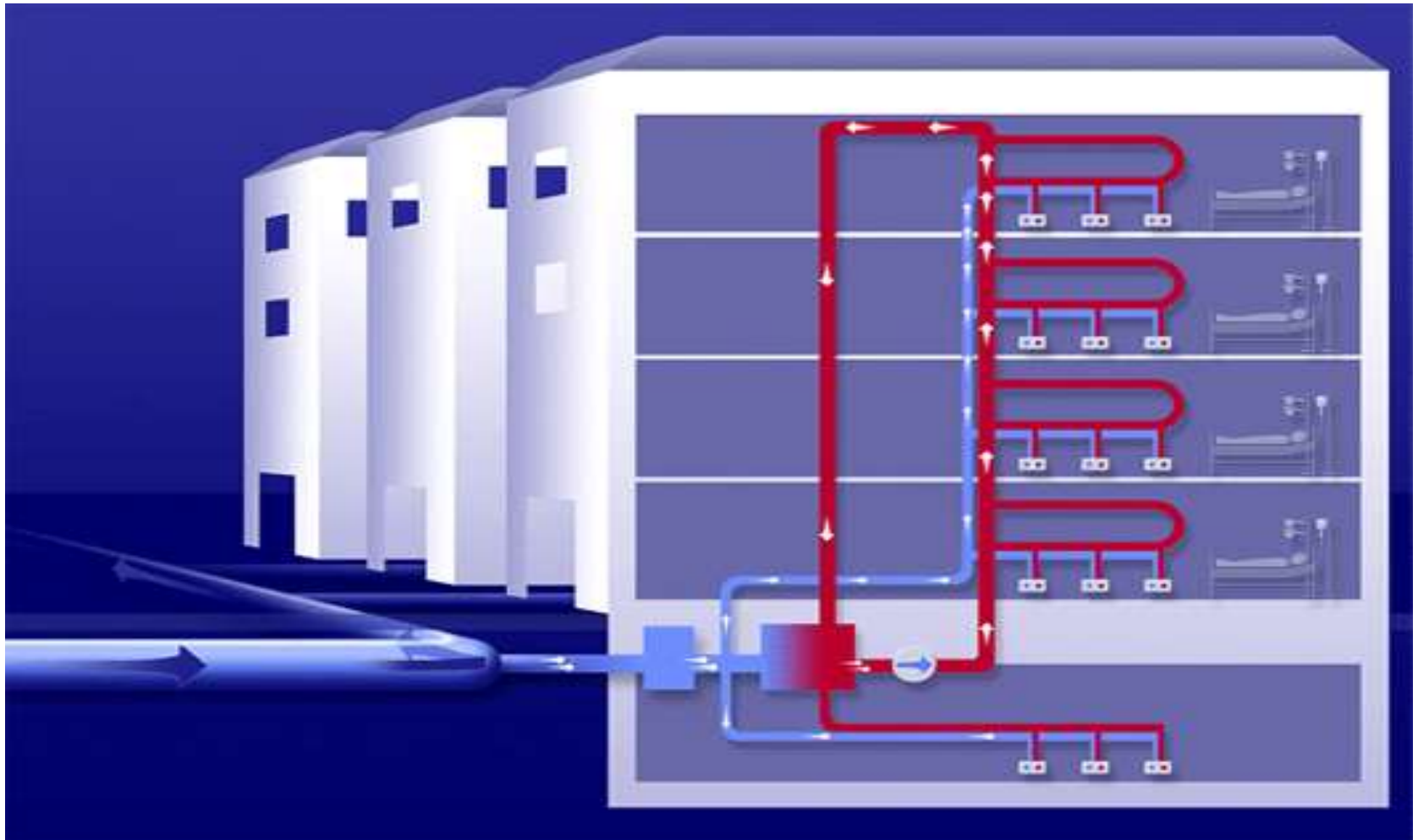
The most likely sources of infection include:

- Water used for showering (potable water)
- Cooling towers (parts of large air conditioning systems)
- Decorative fountains
- Hot tubs



Legionella and or amoeba could increase due to Fe, no residual chlorine, increase In temperature. Don't have to live in Flint to be exposed.

Bacterial numbers increase 10 to 1,000 fold in the Plumbing inside a Building



Biofilm Niche

http://www.nature.com/nature/journal/v523/n7562/fig_tab/nature14660_SV1.html

- Water distribution systems
 - Low disinfectant residual
 - Warm to hot water temperature
 - Proliferate inside protozoan symbionts

- Showers
 - Water faucets
 - Humidifiers
 - Therapy pool
 - Toilets
 - Etc.
- 1) Slough & Detach
2) Aerosolize
- Droplets & Particles
3) Inhalation



<http://www.ufag-laboratorien.ch/en/food-analysis/legionella.html>

Data linking *Legionella* to other water quality

Parameter	Correlations	Reference
Solid	Biofilm, Sediment	19, 30
pH	Increased pH, 5 - 9	19, 31
Temperature	Increased temperature 30 - 49 °C, < 50 °C	27, 31-33
Biotic	Increased protozoan counts Presence of amoeba Presence of algal deposits > 27 HPC/L at 22 °C 3.2 ug/L microbial biomass 3.0 x 10 ⁴ thermophilic bacteria 2.0 CFU/L Fungi Less frequent detection of indicators	21, 27, 31, 33-37
Infrastructure	> 2-20 years old piping > 10 m distance from distribution > 10 story building height continuously circulating systems	27, 32, 34, 38-39

(Derived from Buse et al., 2012)

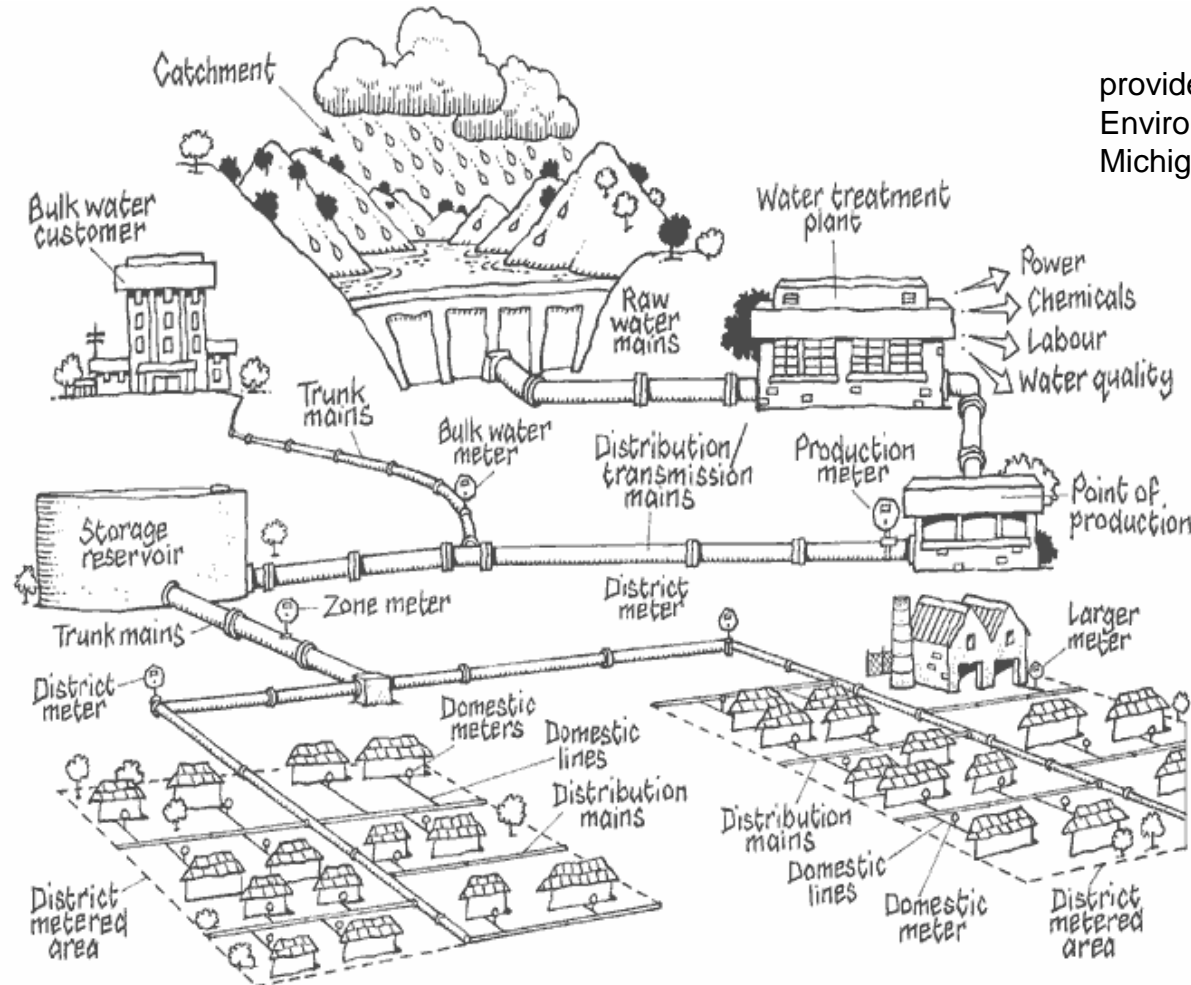
Data linking *Legionella* to other water quality cont.

Parameter	Correlations	Reference
Chemicals	Ca 25 - 94 mg/L Cu < 50 ug/L Fe > 188 ug/L Mg > 0.5 - 19 ug/L Mn > 4 - 6 ug/L Zn > 100 - 290 ug/L	35-36, 39-41
Water Quality	Oxygen level 6 mg/L TOC 6 mg/L NPOC 5.5 mg/L Sulphate 33 mg/L Nitrate 1.2 mg/L ClO ₂ 0.8 - 1.0 mg/L AOC > 1.4 mg/L	36, 42-43

(Derived from Buse et al., 2012)

What is the role environmental monitoring in protection of public health?

provided by Dr. Susan Masten
Environmental Engineering
Michigan State University



Monitoring

- Exposure needs to be assessed:

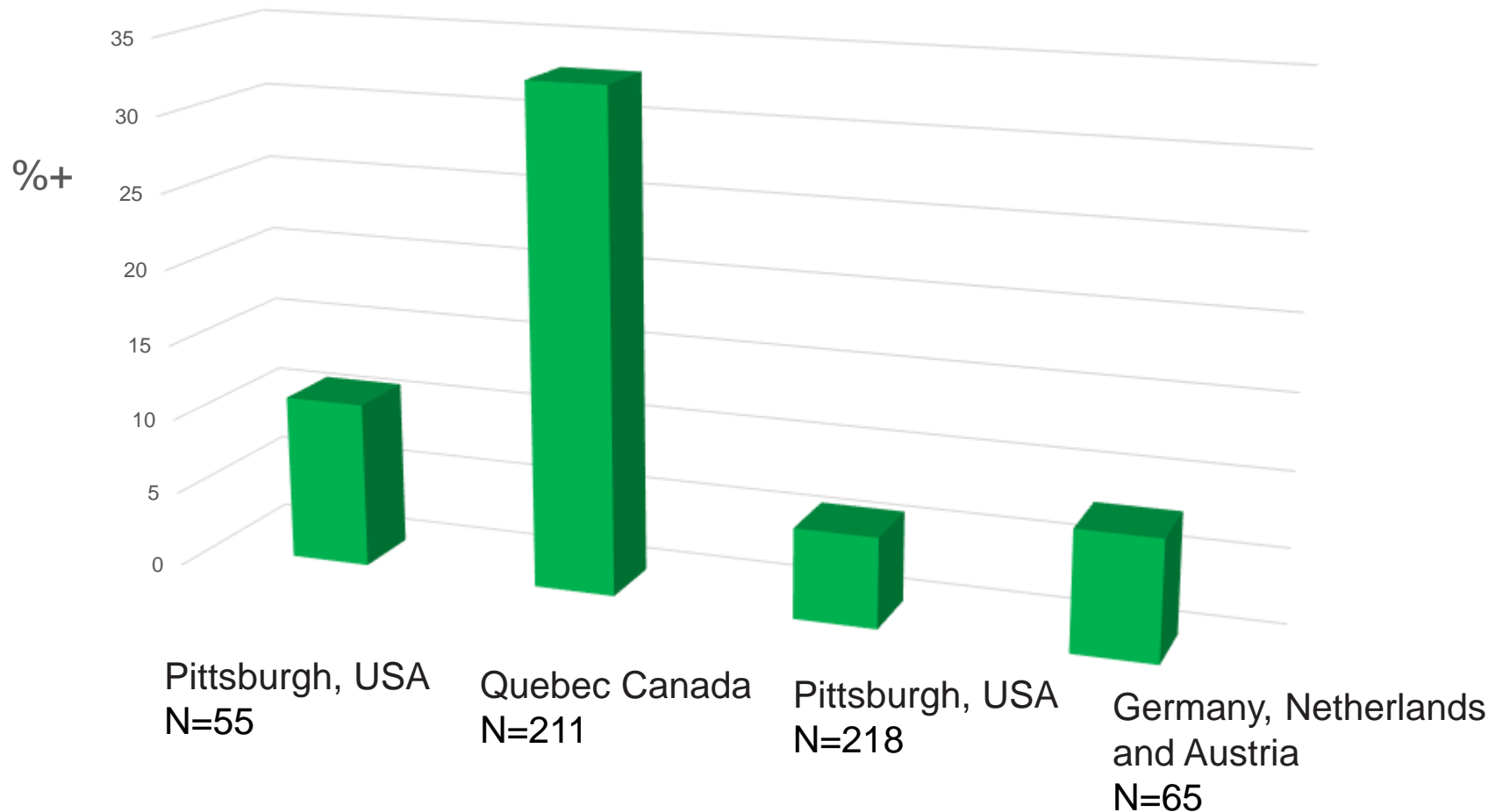
Legionella sampling needs to be undertaken yearly in hospitals and susceptible areas.

Exposure sites: shower heads and taps, fountains, cooling towers

Replication sites: water heaters, pipe systems, biofilms

Composite sampling of households

Home Samples Positive for culturable *Legionella* (L.p. detected)



Positive samples in Pittsburg

- 6% of homes (14/218) were positive for *Legionella pneumophila*
- 22% positive for *Legionella* spp. Had higher levels of iron
- None of the individual had positive antibody tests.

Legionnaires' Disease Contracted from Patient Homes: The Coming of the Third Plague?

Pedro-Botet et al. Eur J Clin Microbiol Infect Dis (2002) 21:699–705

DOI 10.1007/s10096-002-0813-2

704

Table 2 Demographics of 13 cases of Legionnaires' disease acquired from home water supplies

Country	Reference no.	Year published	Age/sex	Cigarette smoker	Chronic lung disease	Immuno-suppression	Outcome	Source	Molecular typing method
USA	[18]	1987	65 M	no	no	CLL	lived	home	none
			55 M	yes	COPD	none	lived	home	MAB
USA	[20, 37]	1987	56 M	no	no	transplant	lived	home	MAB
Italy	[19]	1988	20 M	NA	no	none	lived	home	none
USA	[17]	1992	45 M	yes	no	none	lived	apartment	REA, MAB
			75 F	no	no	diabetes	lived	apartment	REA, MAB
			56 F	no	no	transplant	lived	home	REA, MAB
UK	[21]	1994	52 F	no	no	none	died	home	REA
Netherlands	[22]	1996	50 M	no	no	CLL	lived	apartment	PFGE
UK	[23]	2001	46 M	no	no	transplant	died	home	AFLP
USA	[24]	2001	76 F	yes	no	none	died	apartment	PFGE
Switzerland	[25]	2002	58 F	no	no	transplant	lived	home	PFGE AFLP
Taiwan	[12]	2002	69 M	no	no	Sweet syndrome, myelodysplasia	died	home	PFGE

AFLP, amplified fragment polymorphism; CLL, chronic lymphocytic leukemia; COPD, chronic obstructive pulmonary disease; MAB, monoclonal antibody; NA, not available; PFGE, pulsed-field gel electrophoresis; REA, restriction endonuclease analysis

Table 2 Distribution of *Legionella* species and serogroups in 15 homes (9 cases, 6 controls)

Parameter	Case homes	Control homes
No. of samples positive for legionellae/no. tested	9/113 (8%)	6/32 (19%)
No. of samples positive for <i>L. pneumophila</i> /no. positive for legionellae	7/9	3/6
No. of samples positive for <i>L. pneumophila</i> serogroup 1/no. positive for legionellae	6/9	1/6
No. of samples positive for <i>L. pneumophila</i> serogroup 1/no. positive for <i>L. pneumophila</i>	6/7	1/3

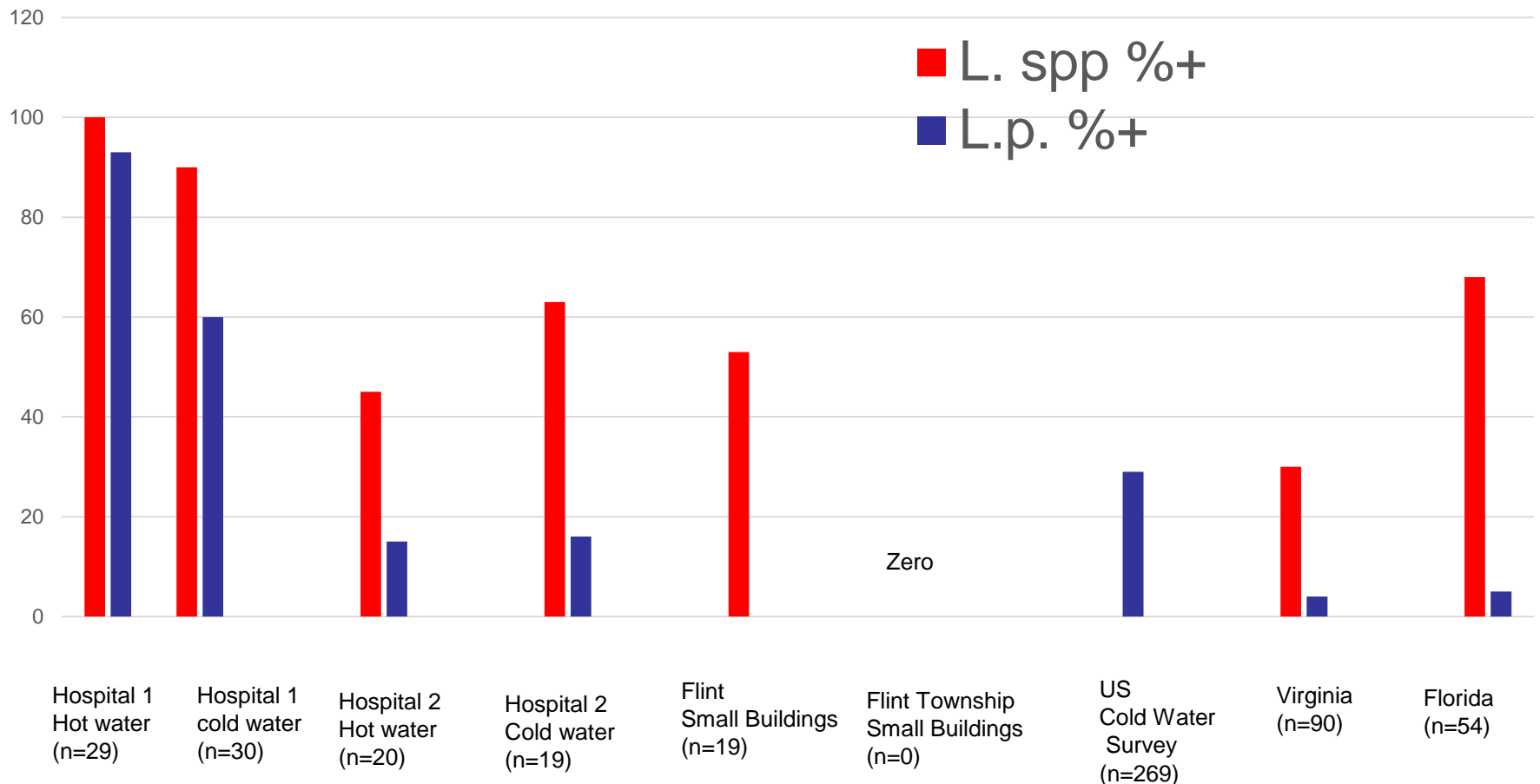
Data demonstrate the need to provide greater specificity

Codony et al. Eur J Clin Microbiol Infect Dis (2002) 21:717–721

DOI 10.1007/s10096-002-0789-y

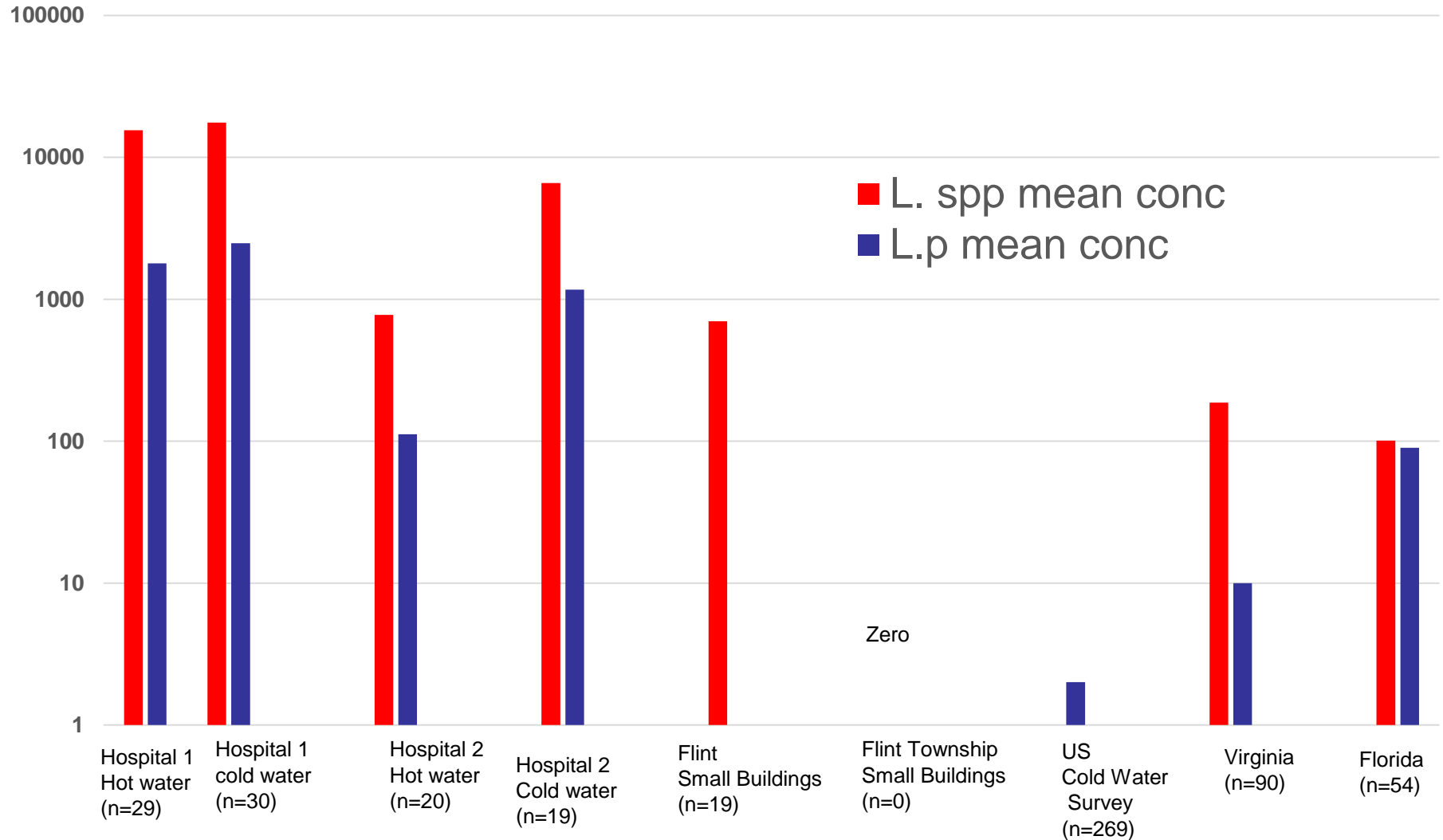
Percentages of samples positive for *Legionella* and L.p (using PCR)

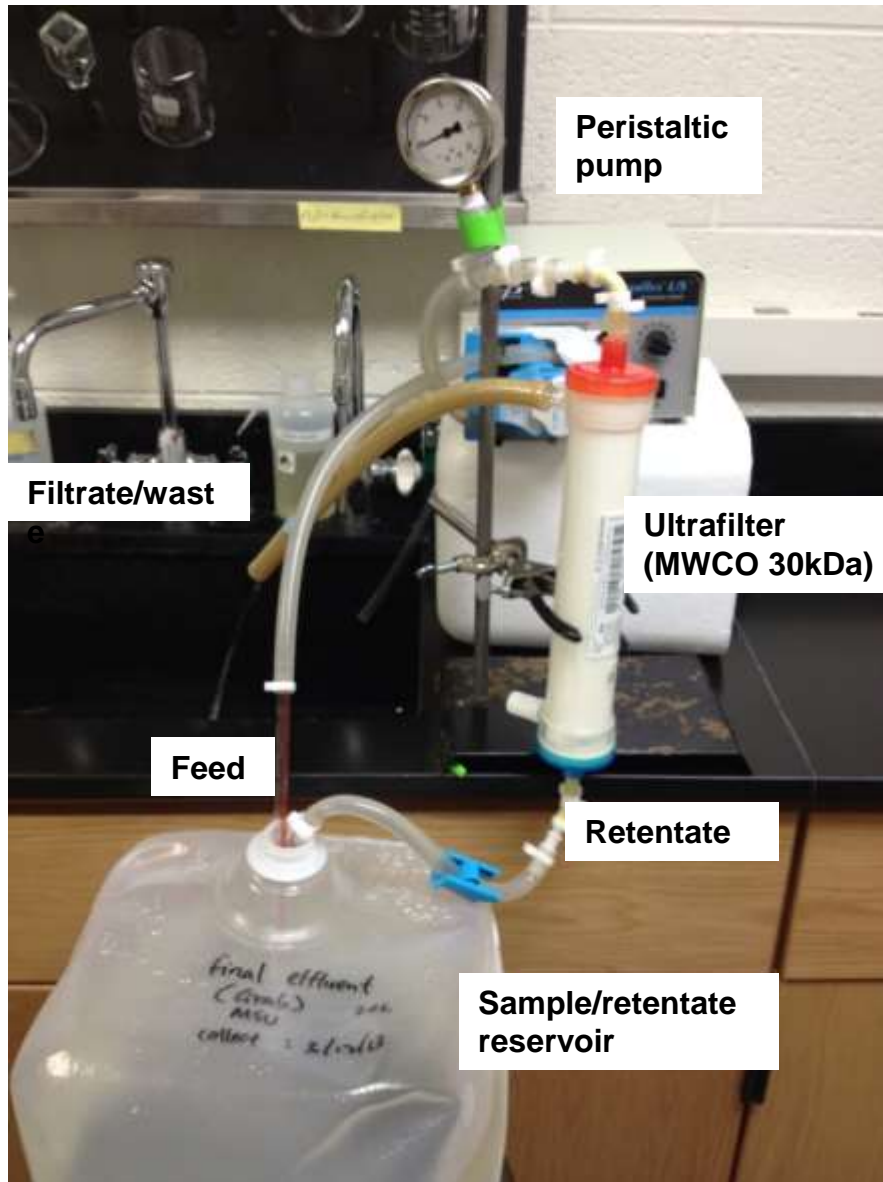
Schwake et al. *Legionella* DNA Markers in Tap Water Coincident with Spike in Legionnaires' Disease in Flint, MI Environ. Sci. Technol. Lett., 2016



Concentrations of *Legionella* and L.p (Gene copies/ml)

Schwake et al. Legionella DNA Markers in Tap Water Coincident with Spike in Legionnaires' Disease in Flint, MI Environ. Sci. Technol. Lett., 2016





IMPROVING SAMPLING

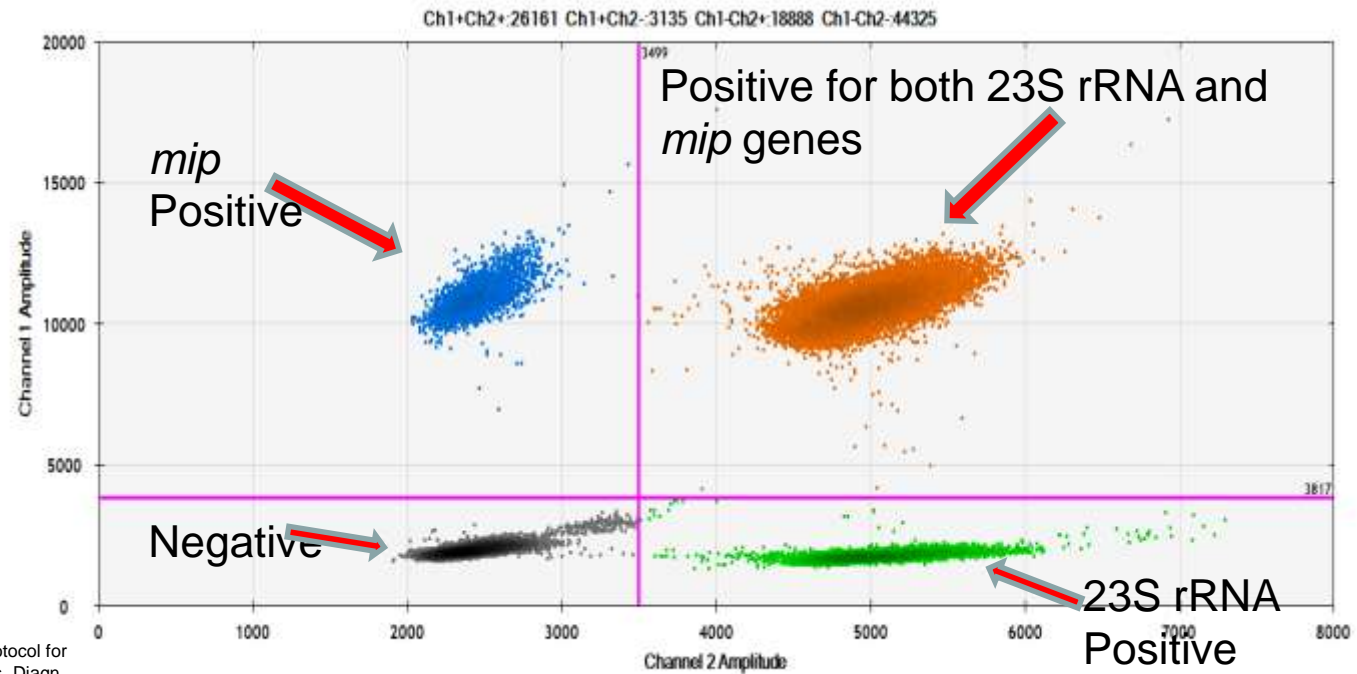
Large volume sampling

Compositing home and building samples

Low-cost ultrafiltration system with disposable hollow fiber filters

ddPCR *Legionella* spp. & *L. pneumophila* duplex

- 23s rRNA gene for all *Legionella* spp.
- *mip* gene for *L. pneumophila*
- > 10,000 tests (droplets) per well



Nazarian, E.J., et al. (2008). Design and implementation of a protocol for the detection of *Legionella* in clinical and environmental samples. Diagn. Microbiol. Infect. Dis. 62:125-132.

Long term needs

- Understand concentrations, how the bacteria is distributed, how it regrows.
- Address relationship to residence time of water in pipes
- Examine if biofilms are hazardous
- Role of water heater kept at 60° C in hospitals, 55 in homes to prevent regrowth
- Role of chemical water quality in distribution systems (hardness, metals, pH, chlorine)
<http://legionella.org/guidelines/>



Thank You!

Any Questions??

