**International Emerging Technology Symposium**

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**May 11, 2016**

# Water Quality, Water Savings and the Water-Energy Nexus Three Issues, One Solution?

By

**Part 1 - Marc Edwards**

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# America's Water Infrastructure is Failing

## Water Mains

- 240,000 leaks/year due to corrosion (EPA 2010)
- $200 billion for safe drinking water/next 10 years (Shanaghan 2012)

## Building Plumbing

- ≈ 750,000 leaks/year
- $1 billion/year for consumers

(Scardina et al. 2007)

Maryland, March 19 2013

13 leaks/foot of copper pipe in one case

# Corrosion

# The New Challenge: Opportunistic Premise Plumbing Pathogens (OPPPs):

# Key Issues

- Why OPPPs, Why Now?
- Taking Responsibility for OPPPs
- OPPPs in green buildings

# Growth of Opportunistic Pathogens

- Primary cause of waterborne disease in US

*Legionella pneumophila*

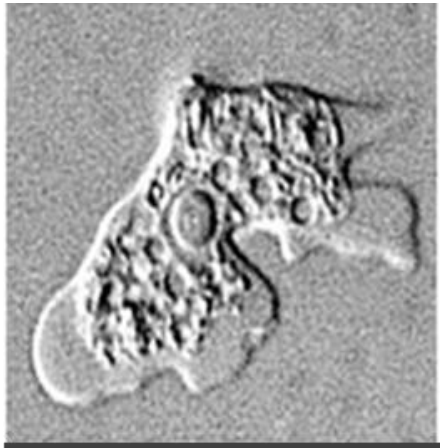
- 8K-18K cases/yr
- $430M/yr
- Cause of all 31 reported respiratory waterborne disease outbreaks 2007-10

*Mycobacterium avium*

- 100 cases/$10^5$ people >60yrs
- $425M/yr
- Only recently linked to drinking water

*Pseudomonas aeruginosa*

- 11,000 HAIs from 1992-93
- No required reporting



*Naegleria fowleri*

- "Brain eating amoeba" – 2 recent high profile cases linked to drinking water

**References: 1-5**

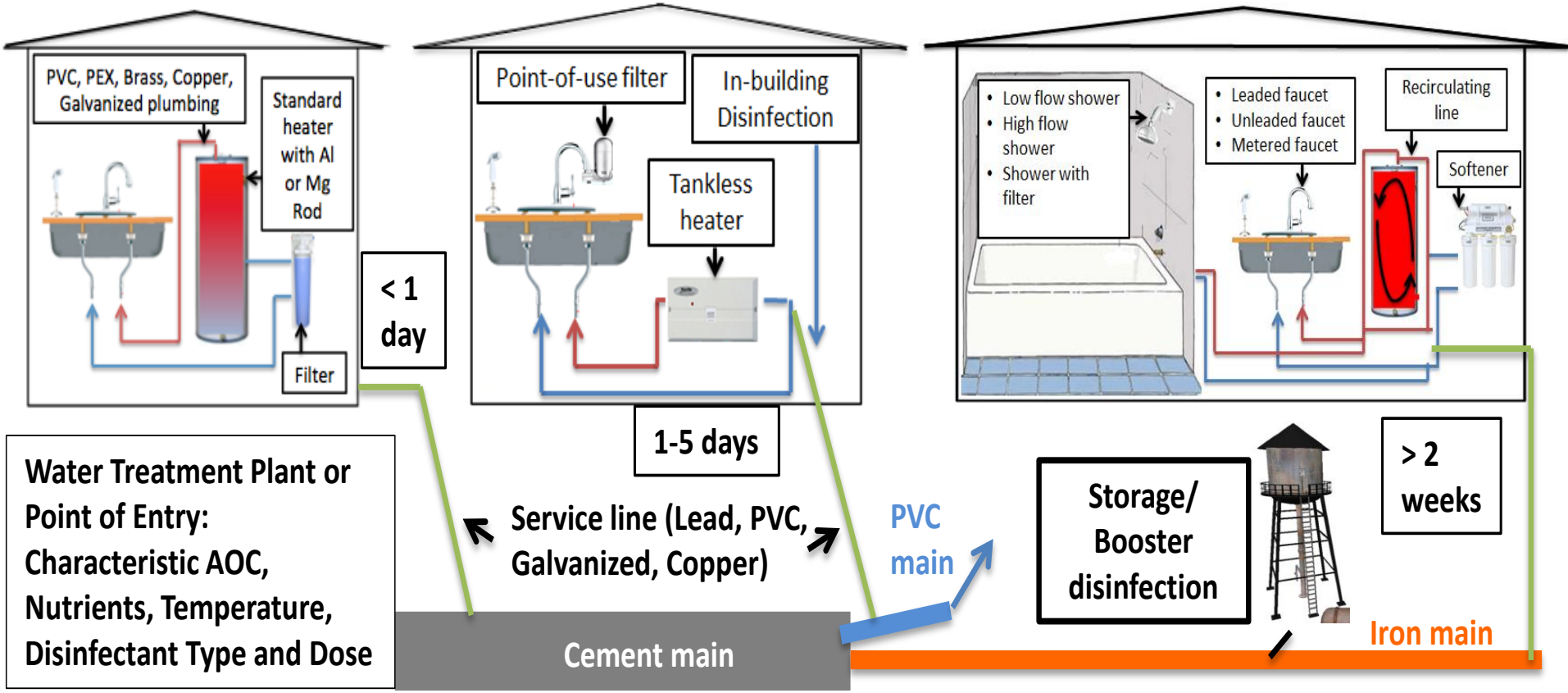
# Why Increasing Incidence of OPPPs?

- Improved detection and diagnosis
- Warming planet and buildings
- More time spent indoors (from 80% to 90% in 20 years)
- Changing demographics and immuno status
  - Rising levels of obesity, elderly, asthma, allergies
- Sustainable buildings and cities?
  - Water conservation/green building/water reuse
  - Tighter buildings

***OPPPs control will be the key water-related public health battlefield of the 21st Century***

# Taking Responsibility for OPPPs

# Amplification of OPPPs



# Engineering Control Strategies

1) Limiting Nutrient Strategies (e.g., AOC)
2) Secondary Residual Type and Dose
3) Upgrade Water Mains
4) **Water Heater Set Point**
5) In-Building Disinfection
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Utility

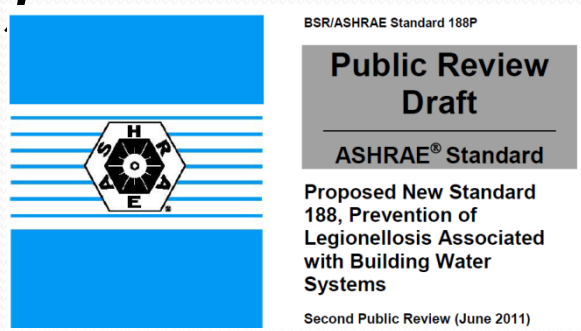
Building Level

# Water Heater Set Point

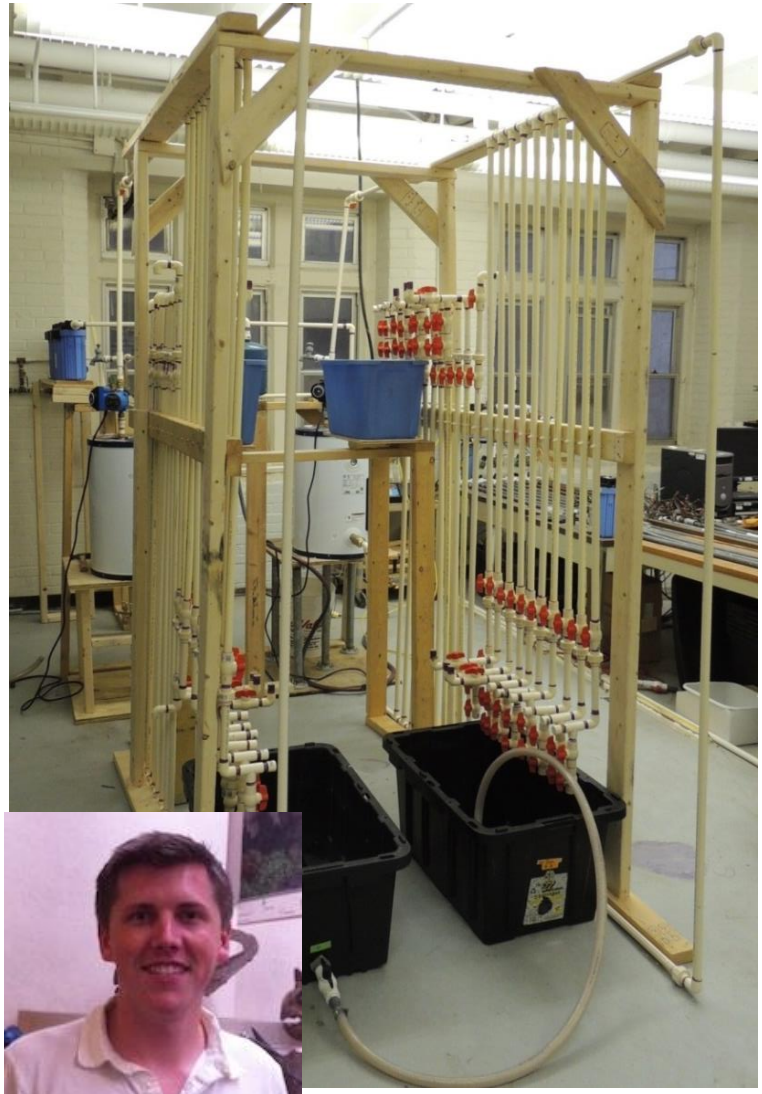
Concept: Achieving temperatures > 60 ° throughout plumbing system severely limits regrowth of all OPPPs

Limitations (Rhoads et al., 2014):

- Not an option in systems with scaling
- Higher "E" costs (scaling, more losses)
- Scalding concerns (probably over-rated)
- Higher temperatures can sometimes mean much more OPPPs at distal taps




# Hot Water Plumbing Rig





William Rhoads

Rhoads *et al. Microbiome* (2015) 3:67
DOI 10.1186/s40168-015-0134-1

Microbiome

RESEARCH Open Access

## Water heater temperature set point and water use patterns influence *Legionella pneumophila* and associated microorganisms at the tap

William J. Rhoads*, Pan Ji, Amy Pruden and Marc A. Edwards

**Abstract**

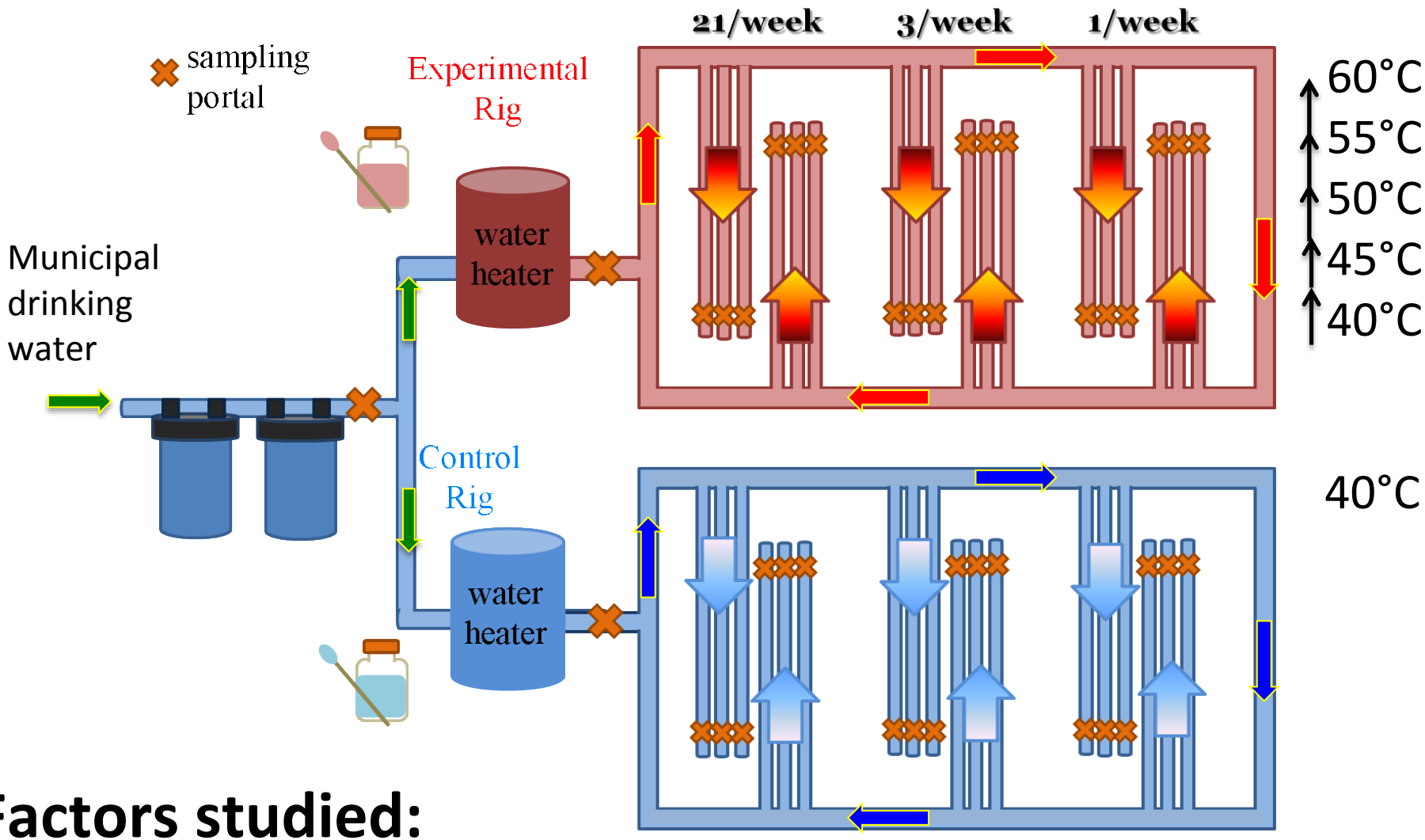
**Background:** Lowering water heater temperature set points and using less drinking water are common approaches to conserving water and energy; yet, there are discrepancies in past literature regarding the effects of water heater temperature and water use patterns on the occurrence of opportunistic pathogens, in particular *Legionella pneumophila*. Our objective was to conduct a controlled, replicated pilot-scale investigation to address this knowledge gap using continuously recirculating water heaters to examine five water heater set points (39–58 °C) under three water use conditions. We hypothesized that *L. pneumophila* levels at the tap depend on the collective influence of water heater temperature, flow frequency, and the resident plumbing ecology.

**Results:** We confirmed temperature setting to be a critical factor in suppressing *L. pneumophila* growth both in continuously recirculating hot water lines and at distal taps. For example, at 51 °C, planktonic *L. pneumophila* in recirculating lines was reduced by a factor of 28.7 compared to 39 °C and was prevented from re-colonizing biofilm. However, *L. pneumophila* still persisted up to 58 °C, with evidence that it was growing under the conditions of this study. Further, exposure to 51 °C water in a low-use tap appeared to optimally select for *L. pneumophila* (e.g., 125 times greater numbers than in high-use taps). We subsequently explored relationships among *L. pneumophila* and other ecologically relevant microbes, noting that elevated temperature did not have a general disinfecting effect in terms of total bacterial numbers. We documented the relationship between *L. pneumophila* and *Legionella* spp., and noted several instances of correlations with *Vermamoeba vermiformis*, and generally found that there is a dynamic relationship with this amoeba host over the range of temperatures and water use frequencies examined.

**Conclusions:** Our study provides a new window of understanding into the microbial ecology of potable hot water systems and helps to resolve past discrepancies in the literature regarding the influence of water temperature and stagnation on *L. pneumophila*, which is the cause of a growing number of outbreaks. This work is especially timely, given society's movement towards "green" buildings and the need to reconcile innovations in building design with public health.

**Keywords:** *Legionella pneumophila*, Hot water, Stagnation, Water use, Temperature

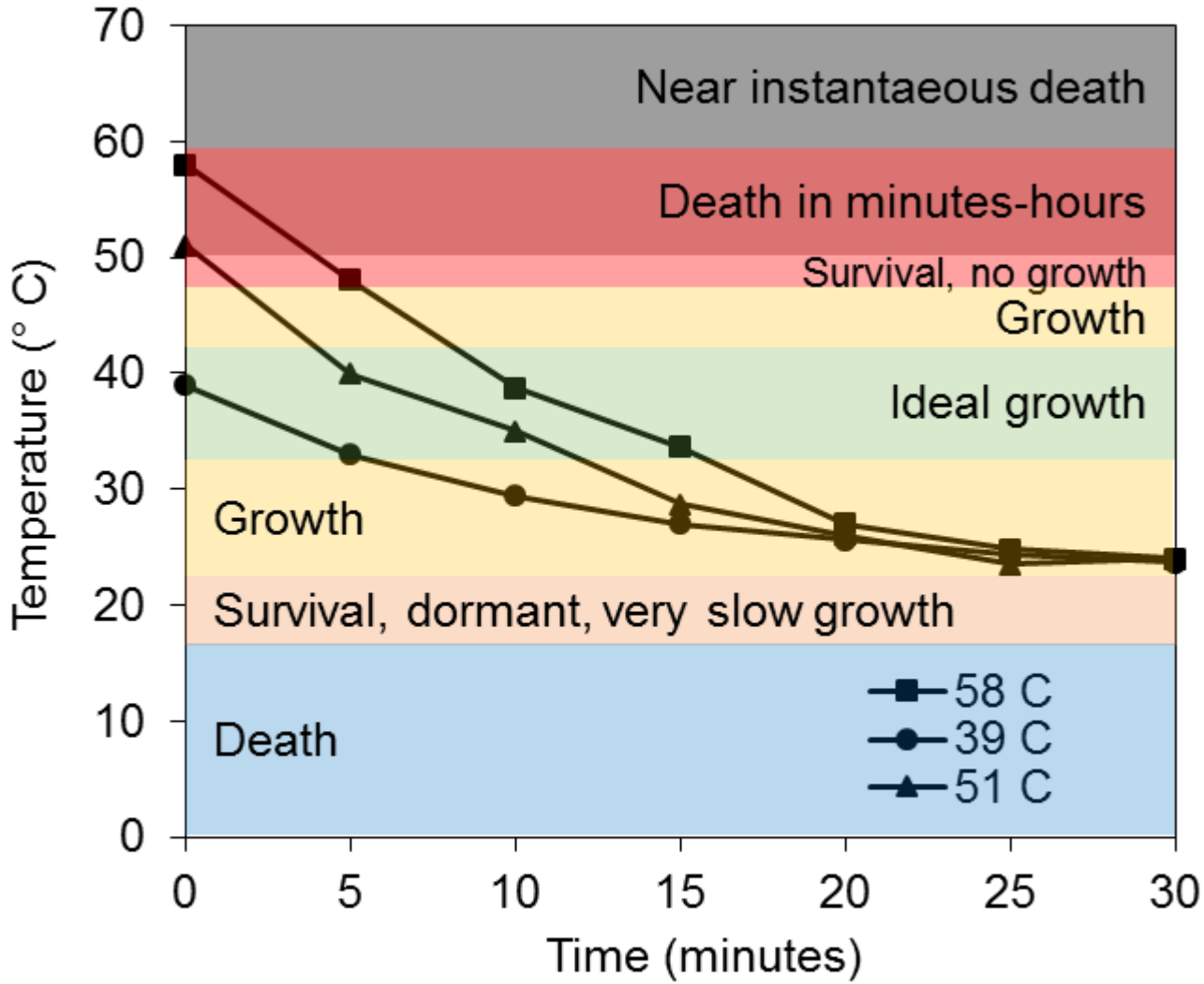
# Simulating Hot Water Plumbing




**Factors studied:**

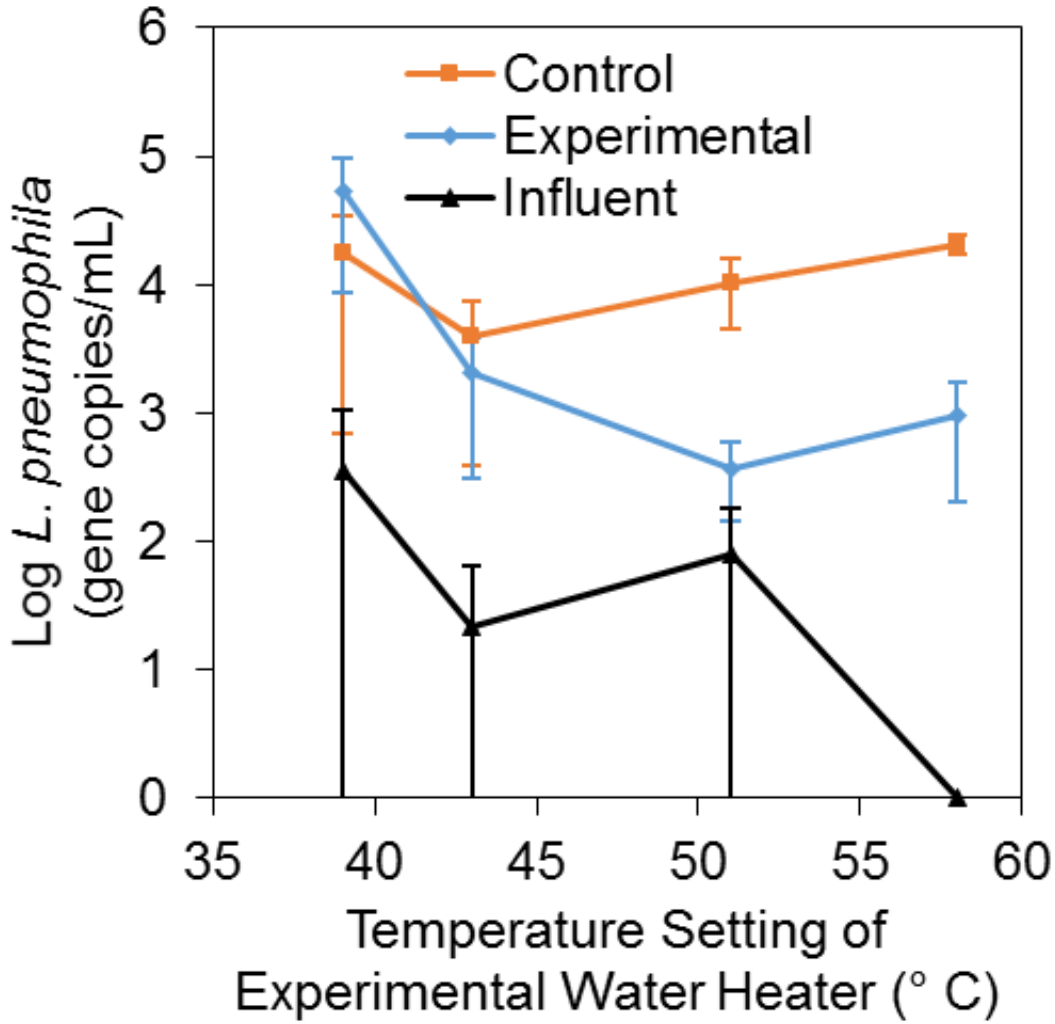
1. Temperature 2. Stagnation 3. Use frequency 4. Pipe orientation

# Temperature x time for *L. pneumophila*




Distal Taps cooled to room T in 20 minutes!

# More *L. pneumophila* re-growth at warm (not hot) T



# Heater Set Point x Use Frequency

"Sweet Spot"

**A *L. pneumophila* concentration (log gene copies/mL)**

| Control System (39° C) | Water Use Freqency Low | Medium | High | Experimental System | Water Use Freqency Low | Medium | High |
|---|---|---|---|---|---|---|---|
| 5 months | 4.2 | 4.2 | 4.1 | Baseline (39° C) | 4.3 | 4.3 | 4.2 |
| 8 months | 4.2 | 3.4 | 3.9 | Exp.1 (42° C) | 3.5 | 3.1 | 3.0 |
| 13 months | 4.3 | 4.7 | 4.3 | Exp. 2 (51° C) | 4.3 | 2.3 | 2.2 |
| 15 months | 5.1 | 4.8 | 4.3 | Exp. 3 (58° C) | 3.4 | 3.2 | 2.7 |

**B *L. pneumophila* regrowth factor (distal taps/recirculating lines)**

| Control System (39° C) | Water Use Freqency Low | Medium | High | Experimental System | Water Use Freqency Low | Medium | High |
|---|---|---|---|---|---|---|---|
| 5 months | 0.8 | 0.9 | 0.7 | Baseline (39° C) | 0.3 | 0.4 | 0.3 |
| 8 months | 4.2 | 0.7 | 2.1 | Exp.1 (42° C) | 1.5 | 0.5 | 0.5 |
| 13 months | 1.9 | 5.6 | 1.9 | Exp. 2 (51° C) | 68.2 | 0.7 | 0.6 |
| 15 months | 5.5 | 3.2 | 1.0 | Exp. 3 (58° C) | 2.7 | 1.6 | 0.5 |

**C Total *L. pneumophila* yield per week (log gene copies)**

| Control System (39° C) | Water Use Freqency Low | Medium | High | Experimental System | Water Use Freqency Low | Medium | High |
|---|---|---|---|---|---|---|---|
| 5 months | 6.9 | 7.4 | 8.1 | Baseline (39° C) | 7.0 | 7.5 | 8.2 |
| 8 months | 6.9 | 6.6 | 7.9 | Exp.1 (42° C) | 6.2 | 6.2 | 7.0 |
| 13 months | 7.0 | 7.9 | 8.3 | Exp. 2 (51° C) | 7.0 | 5.5 | 6.3 |
| 15 months | 7.8 | 8.0 | 8.4 | Exp. 3 (58° C) | 6.1 | 6.4 | 6.7 |

# Engineering Control Strategies

1) Limiting Nutrient Strategies (e.g., AOC)
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Utility

Building Level

Log concentration (gene copies/mL)

No Chloramine → Chloramine

10-100X Less L. pneumophila

| Target Gene | Orientation | Low Use | | | dium se | | High Use |
|---|---|---|---|---|---|---|---|
| *L. pneumophila* | Recirc | 4.2 | | | 2.2 | | |
| | No Mixing | 4.5 | 4.0 | 4.0 | 2.3 | 2.2 | 1.9 |
| | Mixing | 5.0 | 4.4 | 4.4 | 3.1 | 2.5 | 2.4 |
| *Mycobacteria* spp. | Recirc | 3.6 | | | 4.4 | | |
| | No Mixing | 5.0 | 4.5 | 4.8 | 4.9 | 4.7 | 4.9 |
| | Mixing | 5.2 | 4.5 | 4.8 | 6.0 | 5.7 | 5.2 |

10-50X MORE Mycobacteria spp.

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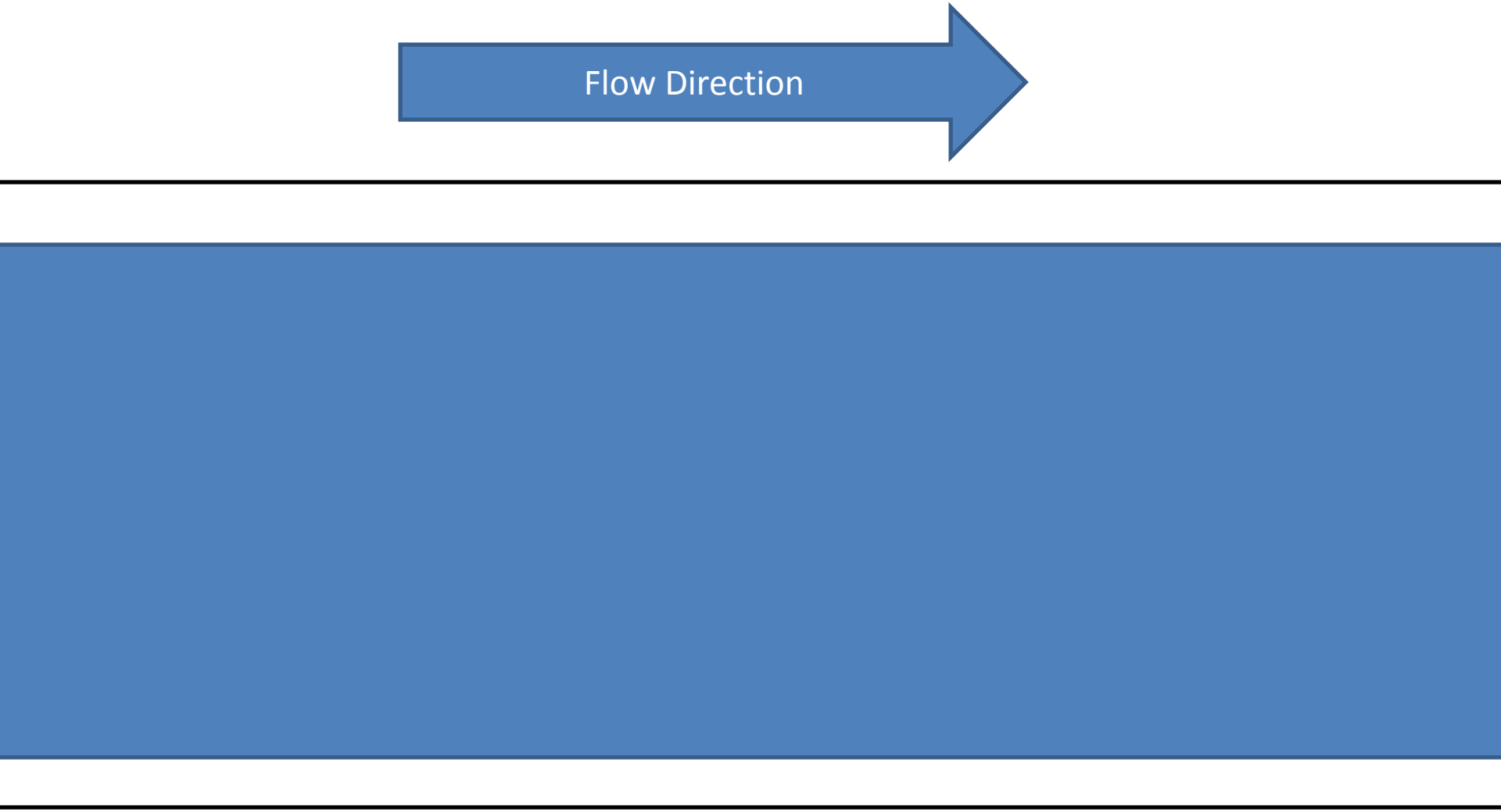
# Flow Rate (Pipe Velocity) Conceptual Model



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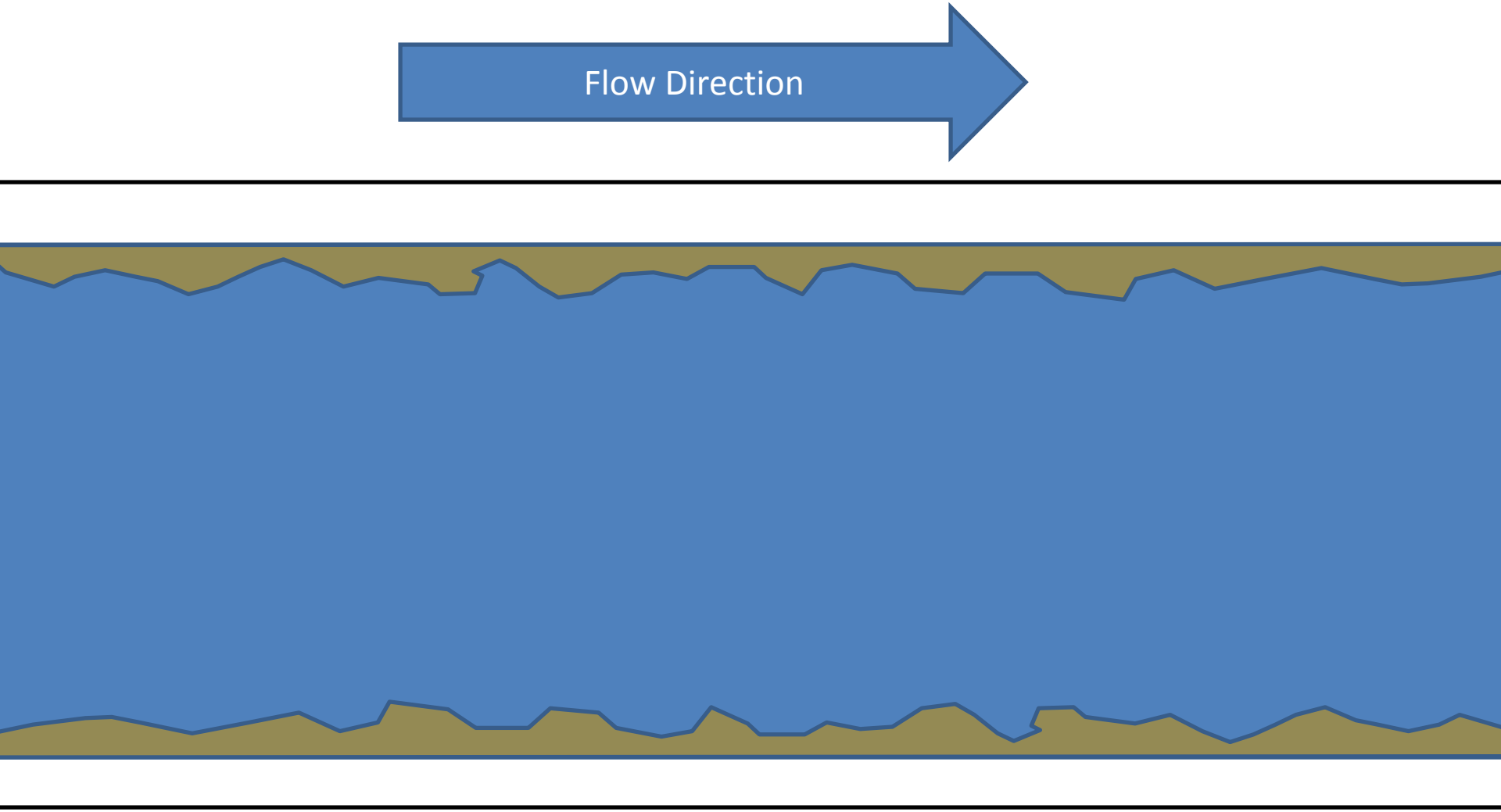

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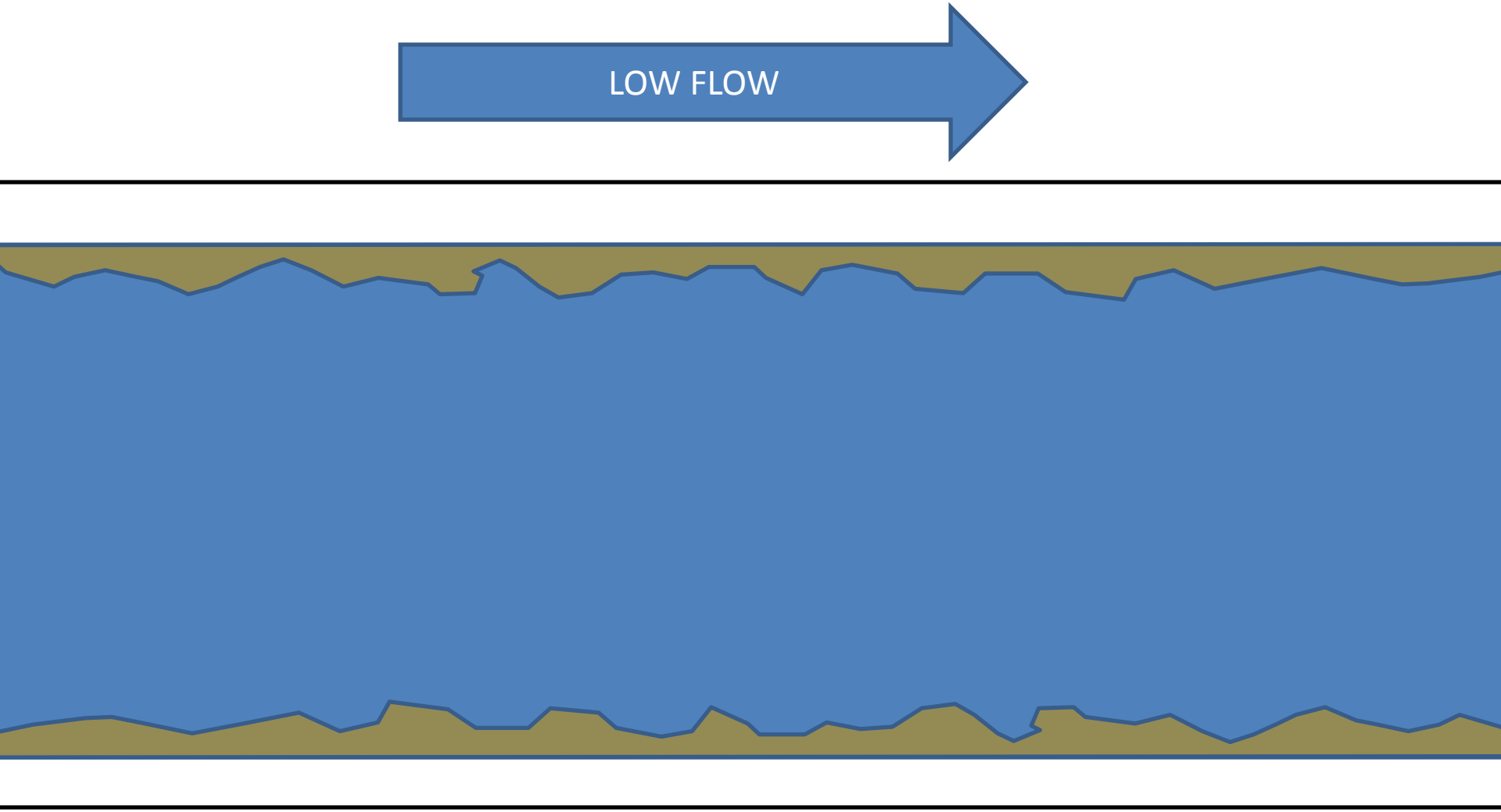

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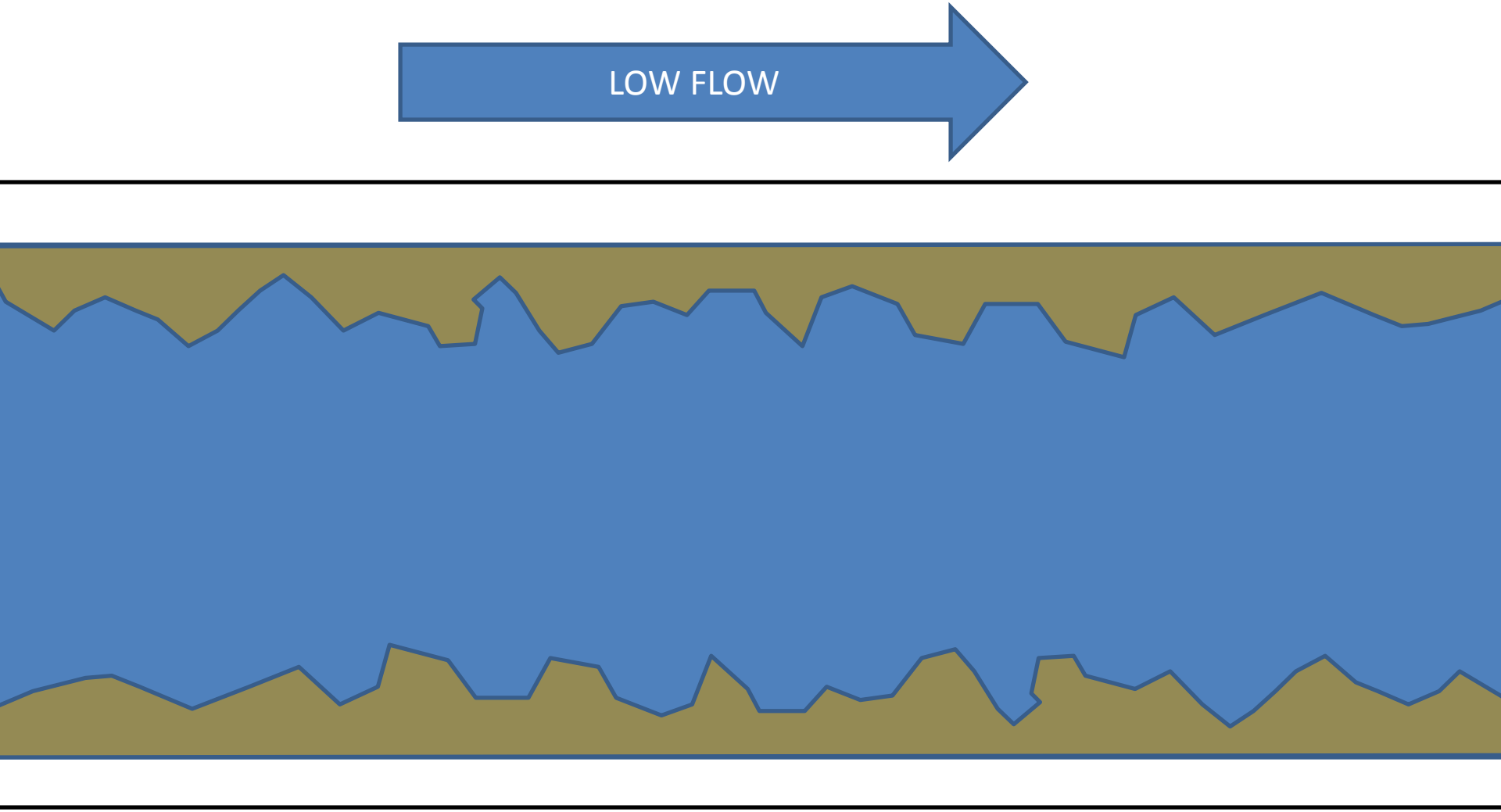

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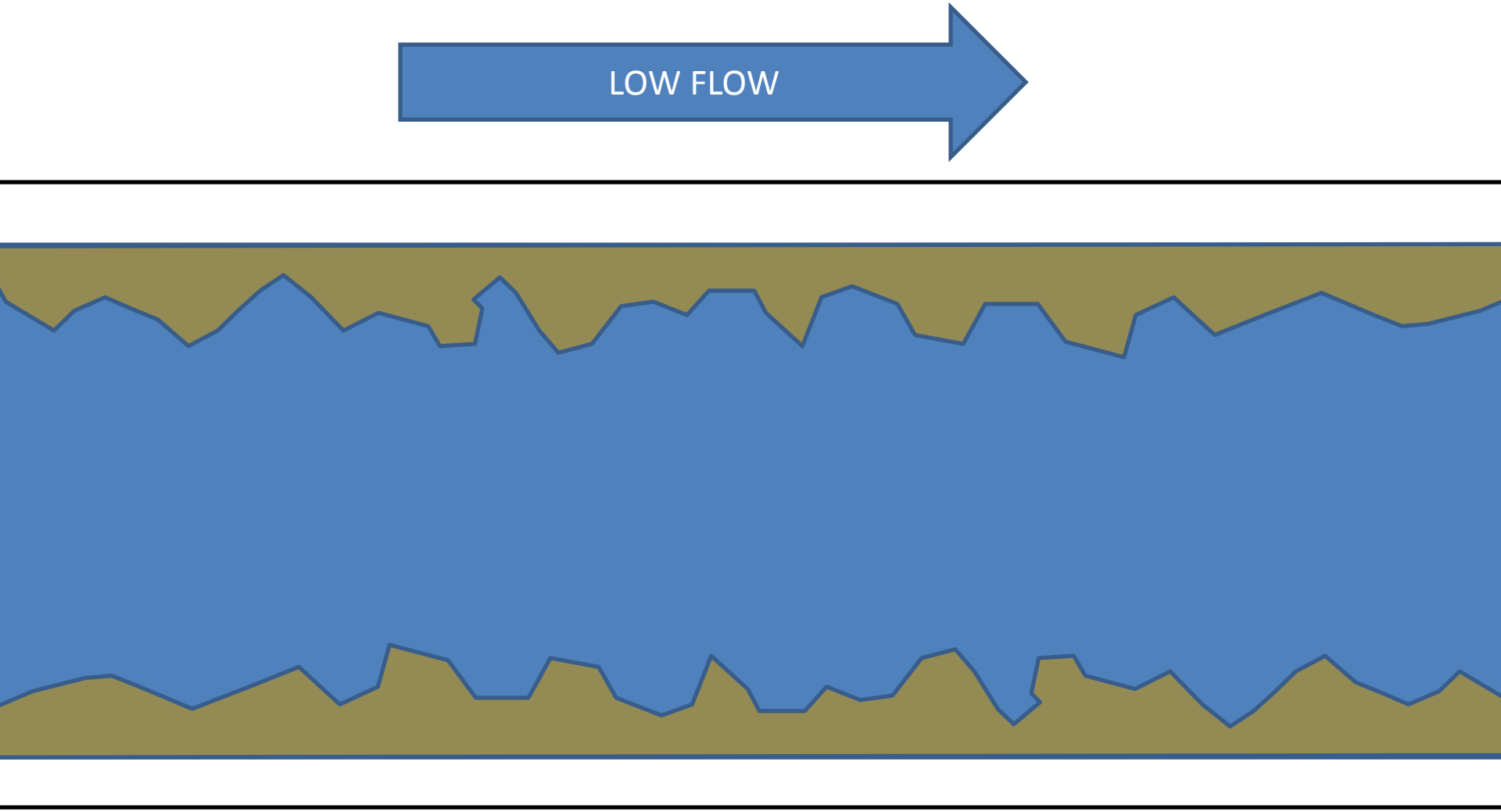

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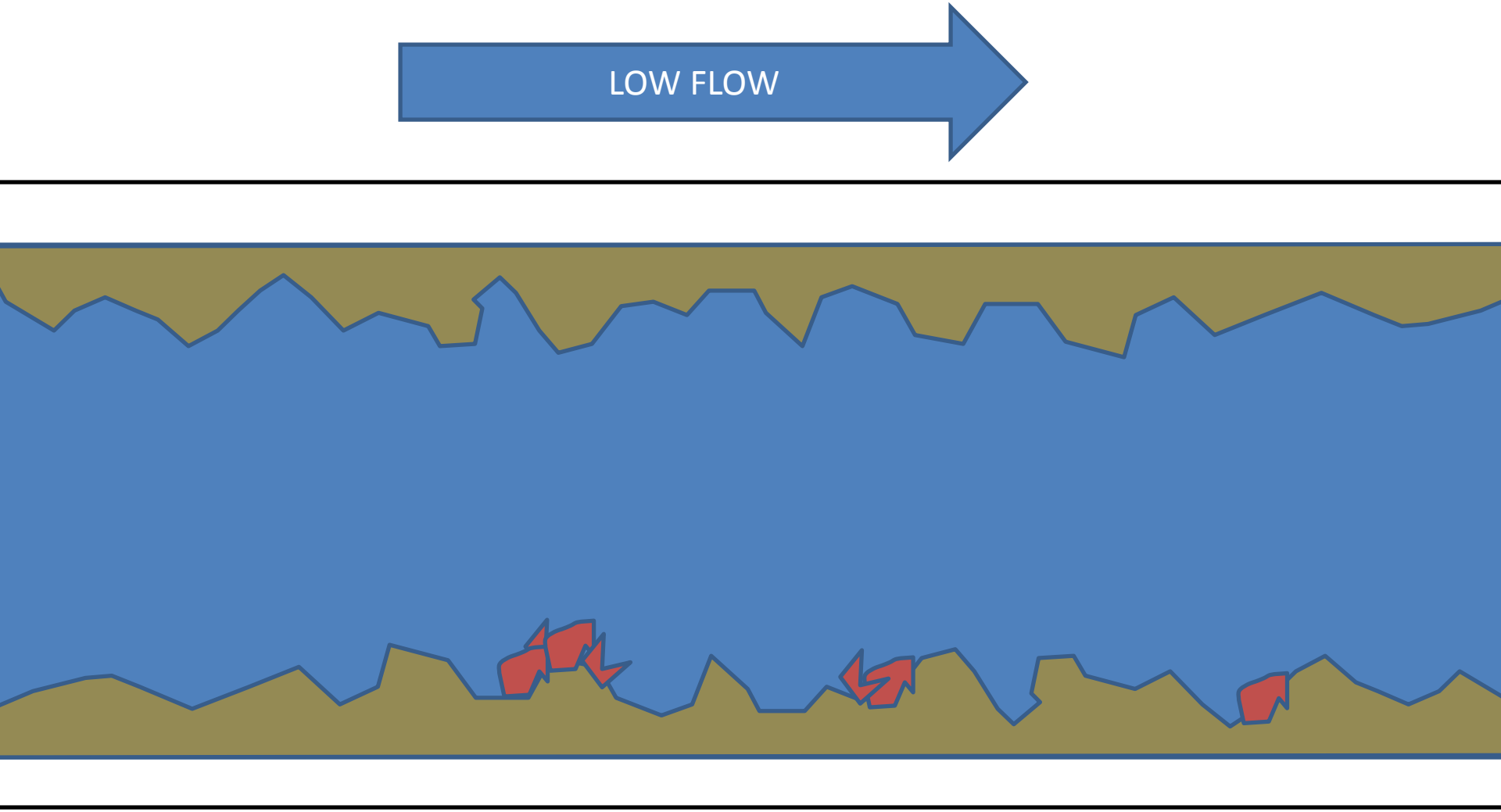

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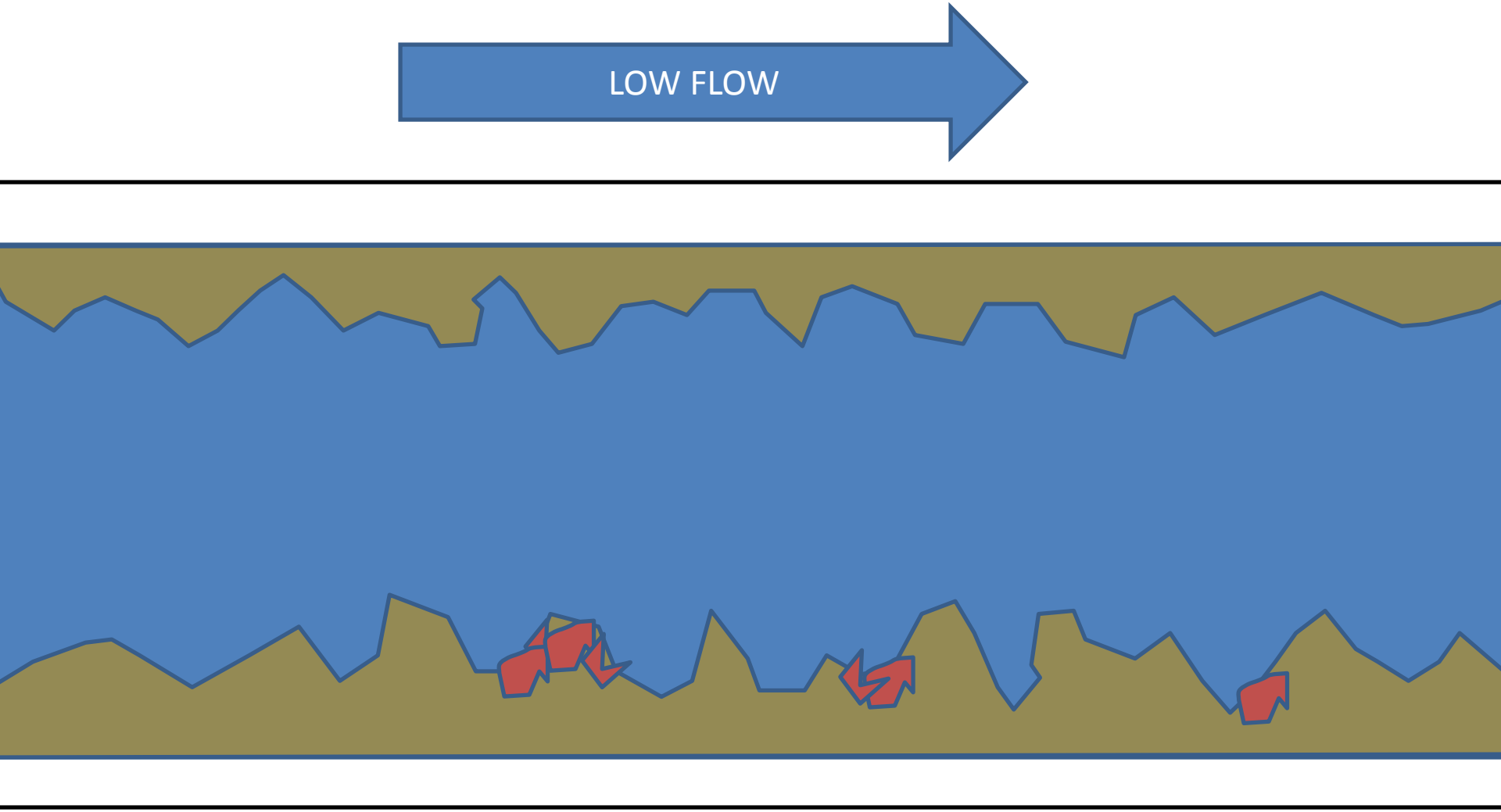

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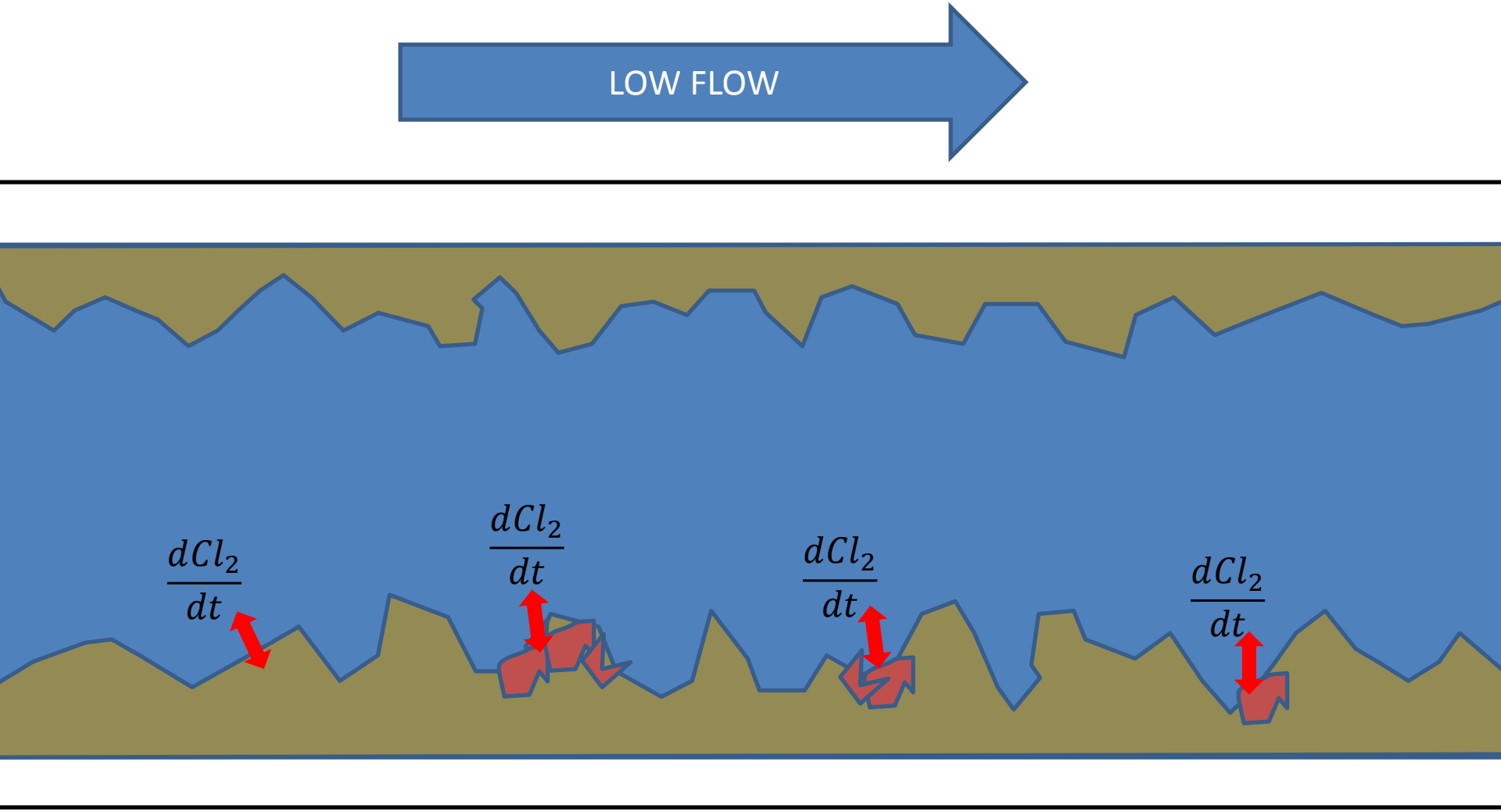
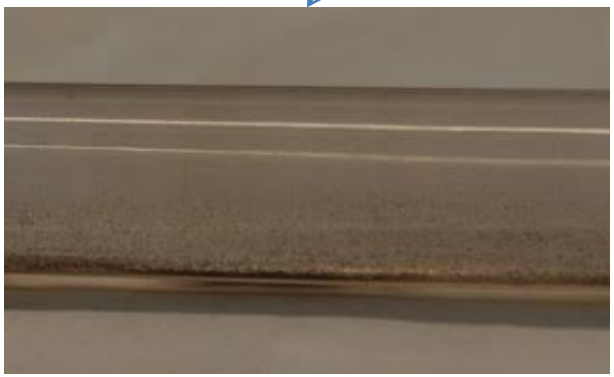


# Proving the Obvious

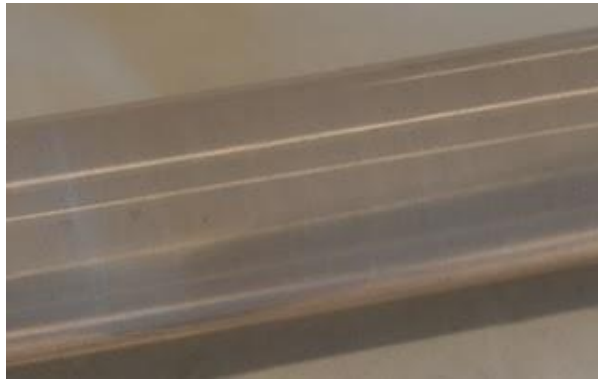
Clear PVC after repeated flushes with water containing humic acid

0.2 gpm
82% retained

0.6 gpm
60% retained



2.6 gpm
8% retained



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DOI: 10.1089/ees.2012.0514

# Role of Hot Water System Design on Factors Influential to Pathogen Regrowth: Temperature, Chlorine Residual, Hydrogen Evolution, and Sediment

Randi H. Brazeau[1,*] and Marc A. Edwards[2]

[1]Department of Earth and Atmospheric Sciences, Metropolitan State University of Denver, Denver, Colorado.
[2]Department of Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Received: December 19, 2012 Accepted in revised form: July 13, 2013

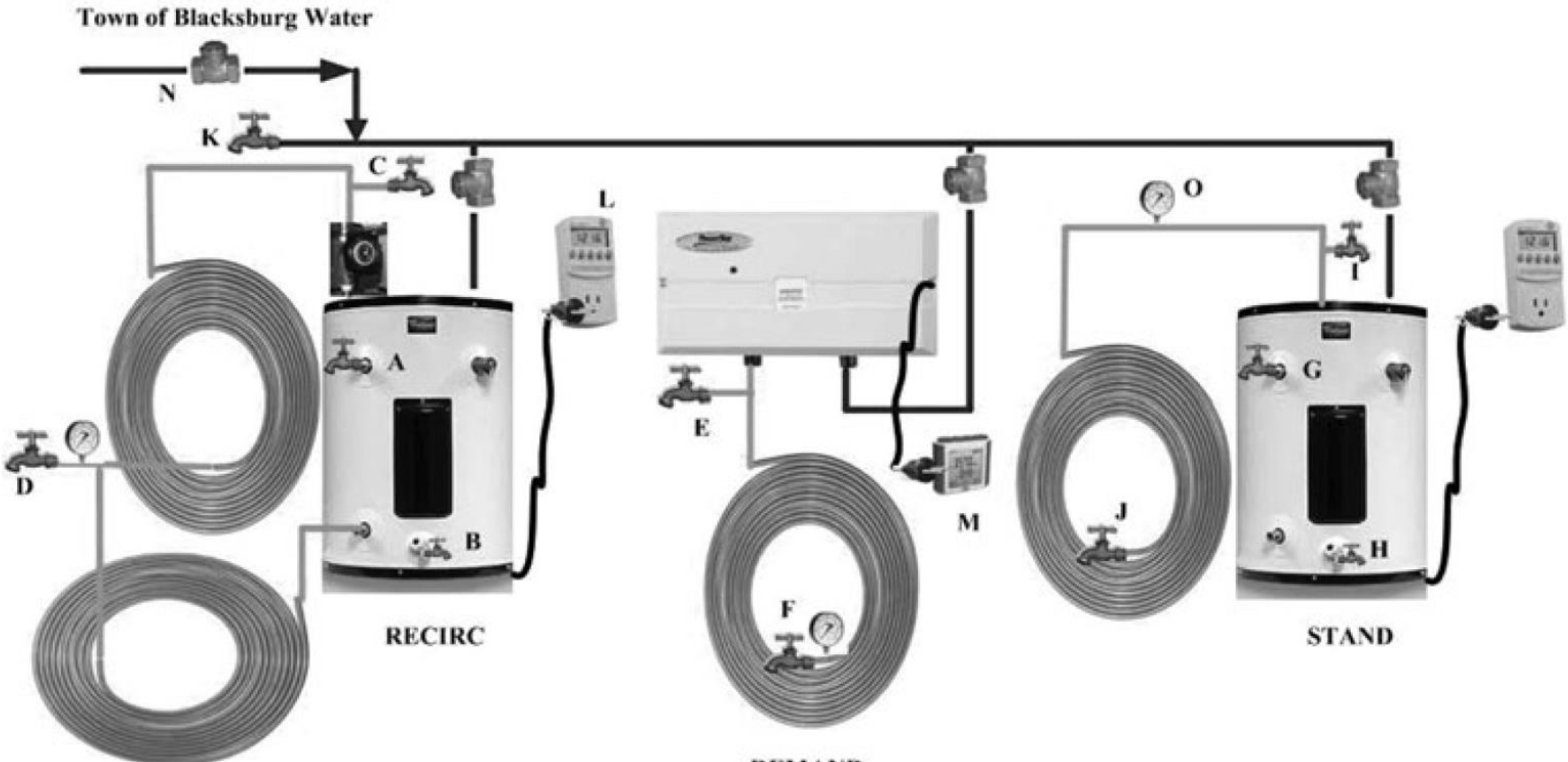

Table 6. Key Differences Between Physical Parameters that May Influence Pathogen Propagation

| | System | | |
|---|---|---|---|
| | *STAND* | *RECIRC* | *DEMAND* |
| Temperature | Tank: Stratifies; bottom as much as 25°C cooler than top<br>Pipes: Cool to ambient (25°C) | Tank: Homogenous<br>Pipes: Heated to tank temperature | Tank: Not Applicable<br>Pipes: Cool to ambient (25°C) |
| Total chloramine residual | 24–66% higher than RECIRC in bulk water | Improved delivery of disinfectant to biofilm | Virtually no decay from distribution system levels |
| Hydrogen; sediment | $H_2$ lower than RECIRC | Circulation delivers $H_2$ directly to pipe biofilm | Extremely low $H_2$; no sediment accumulation |
| DO | Overall higher than RECIRC | Lower DO leads to increased growth of microaerophile | Highest levels of DO |
| Total copper | 6–13 times lower than RECIRC | 310–750 ppb | Similar to STAND |
| Flow reversal; mass transport to pipe wall | None, low transport | Flow reversal in pipes, high transport | None |

# Engineering Control Strategies

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# Buildings with high water age are more likely to be colonized with opportunistic pathogens

| Building | Water Age | Cause of Water Age | Pathogens detected? |
|---|---|---|---|
| LEED office | 8 days | Large # of infrequently used fixtures | Yes |
| Net-zero office | 2-6 months | Rainwater cistern | Yes |
| Net-zero energy house | 2.5 days | Solar water heater | Yes |
| Conventional House | <1 day | NA | No |

# Acknowledgements


- Water Research Foundation
  - Project 4379: Literature Review and Prioritization of OPPPs Research
  - Project 4383: Water Quality Problems in Green Buildings
  - Project 4251: Relationship Between Biodegradable Organic Matter and Pathogen Concentrations in Premise Plumbing
- Alfred P. Sloan Foundation Microbiology of the Built Environment Program
- National Science Foundation Grants 1033498 and 1336550
- Copper Development Association
- **Tim Keane/Consumers/Managers on the OPPPs Front line**

# Conclusions:

- Solutions that can be implemented by utilities
  - Maintaining higher chlorine residuals
  - Upgraded infrastructure
- Solutions that can be implemented by building owners
  - Higher temperatures
  - In building disinfection
  - Flow velocity control
  - Heater type and operation
  - Water age

# Thank You!

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Project 4383: Green Building Design Water Quality Considerations

Microbiology of the Built Environment

Co-authors:

William Rhoads

Amy Pruden

Edwards' Research Group

Collaborator:

Annie Pearce

# Lack of corrosion control = Increased *Legionella*

1. More bacteria “food” in river
2. Iron corrosion = more iron entering buildings’ pipes
3. High iron corrosion removed chlorine disinfectant


# GENESEE COUNTY LEGIONNAIRES' OUTBREAKS

## Flint learns of Legionnaires' disease spike as water crisis continues

By Ralph Ellis and Sara Ganim, CNN

Updated 8:13 PM ET, Wed January 13, 2016

## Legionella Outbreak in Flint Leads to 87 Cases, 10 Deaths; Water Crisis Connection Unclear

Published: Jan 14 2016 12:00 AM EST | By Ada Carr | weather.com