Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health

Overview, status, and projected timeline
Andrew Whelton, Jade Mitchell, Joan Rose, Juneseok Lee, Pouyan Nejadhashemi, Erin Dreelin, Tiong Gim Aw, Amisha Shah, Matt Syal, Maryam Salehi

November 2020
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Goal and Objectives

To better understand and predict water quality and health risks posed by declining water usage and low flows

1. **Improve the public’s understanding of decreased flow** and establish a range of theoretical premise plumbing flow demands from the scientific literature and expert elicitation with our strategic partners

2. **Elucidate the factors and their interactions that affect drinking water quality** through fate and transport simulation models for residential and commercial buildings

3. **Create a risk-based decision support tool** to help guide decision makers through the identification of premise plumbing characteristics, operations and maintenance practices that minimize health risks to building inhabitants.
## Overview of Major Activities

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### Obj 1. Water Conservation Trends
- Review & Info. Syn. Workshop

### Obj 2. Effect of Flow on Water Quality
- Residential – 1 year chem/micro
- Residential – Pathogen exposure
- Residential – Water Age/HRT
- Residential – Hydraulics
- Residential – Fixture prediction
- Residential – Rainwater switch
- Residential – Integrative Hydro-WQ model
- LEED School Bldg – Chemistry / Microbiology
- LEED School Bldg – Pathogens
- LEED School Bldg – Pathogen exposure
- LEED Univ Bldgs – Chemistry / Microbiology
- LEED Office Bldg – Chemistry / Microbiology
- Experiment – GIP/PEX plumbing
- Experiment – Metal deposition in plumbing
- Experiment – Building plumbing TTHMs
- Experiment – PEX TTHMs and leaching
- Experiment – Chem/Microbiology
- Int. Hydro–Fate WDS/Prem Model
- Risk Models with Building Model

### Obj 3. DST Development
- Development Workshop Upgrade
OBJECTIVE 1. Improve the public’s understanding of decreased flow and establish a range of theoretical premise plumbing flow demands from the scientific literature and expert elicitation with our strategic partners.
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<tr>
<td>Residential Building City Water Chemistry and Microbiology 4 month startup:</td>
<td><a href="https://doi.org/10.1016/j.chemosphere.2017.11.070">https://doi.org/10.1016/j.chemosphere.2017.11.070</a></td>
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<td>Residential Building Reverse QMRA for <em>P. aeruginosa</em> Exposure:</td>
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<td>MSU-Purdue-Manhattan Published</td>
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<td>Water Quality in Mixed GIP-PEX Plumbing:</td>
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<td>Synthesis Study: Stagnation Water Quality Impact Review:</td>
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Published... so far
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<tr>
<td>LEED Institutional Buildings Chemistry and Microbiology Study (Gim Aw et al.)</td>
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<td>ID variables that influence legionella in building plumbing (Julien et al.)</td>
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<tr>
<td>Enumeration and Characterization of Five pathogenic Legionella species from Large Research and Educational Buildings (Logan et al.)</td>
<td>MSU</td>
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<td>The Occurrence of 5 Pathogenic Legionella species from Source (Groundwater) to Exposure (Taps and Cooling Towers) In a Complex Water System (Logan et al.)</td>
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<td>Residential Building Upstream Fixture Water Use Prediction Study (Kropp et al.)</td>
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<td>Influence of thermal gradients on legionella in residential plumbing (Julien et al.)</td>
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<td>Synthesis Study: Copper in Schools (Montagnino et al.)</td>
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<td>Risk Based Decision Support Tool (Nedjashimi et al.)</td>
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<td>Planning</td>
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<td>Synthesis Study: Plumbing Safety of the Future</td>
<td>Purdue-MSU-UM-Manhattan-Tulane</td>
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And more…. 
Thermocouples throughout piping, 1x /sec
Indoor air temperature, 1x /sec
Flowrates at every fixture, 1x /sec
Energy use per device, 1x /sec

www.ReNEWWHouse.com

The Most Monitored Home in America
West Lafayette, Indiana
Less than 100 yards from Purdue
3 Bedroom, 1.5 baths
Water saving fixtures
Trunk-and-Branch design
PEX piping
Renovated in 2014

October 2017-October 2018
30,000+ individual water quality measurements completed - does not include flow monitoring, pressure monitoring, or qPCR
2.64 billion online plumbing related measurements
Today, we’ll share some emerging results

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<th>Time</th>
<th>Activities</th>
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<td>1:50 to 3:00 pm</td>
<td>Please post questions in the chat box during the presentations. Andrew Whelton will compile them and during his talk ask each speaker to explain and/or follow-up after the meeting.</td>
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<th>Speaker</th>
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<tbody>
<tr>
<td>Andrew Whelton/Purdue</td>
<td>Project overview, status, and timeline</td>
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<tr>
<td>Liz Montagnino/Purdue</td>
<td>Office building water safety: The role of weekend stagnation</td>
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<tr>
<td>Tiong Gim Aw/Tulane</td>
<td>Microbiology of a school during Summer and Fall seasons</td>
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<td>Alshae Logan/MSU</td>
<td>Microbiology of large institutional buildings</td>
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<td>Ryan Julien/MSU</td>
<td>Identifying variables that influence Legionella concentrations</td>
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<td>Ian Kropp/MSU</td>
<td>Bootstrap Aggregated Decision Tree Classification of End-use Events</td>
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<td>Maria Palmegiani/Manhattan-Purdue</td>
<td>Development of the integrative hydraulic and water quality model</td>
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<td>Ryan Julien/MSU (w/ Drexel)</td>
<td>Comparing risks across building water use types with QMRA</td>
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<tr>
<td>Andrew Whelton/Purdue</td>
<td>Next steps</td>
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</table>
Extra Slides
This will be the integrative water quality-hydraulic model for a single-family home

- October 2017-November 2018
- Continuous monitoring of water flow, air and water temperature at service line and all plumbing components = 2.64 billion data points
- Pressure monitoring continuous during water sampling, 2-3 week periods
- More than 222,223 labor hours for water sampling and analysis (does not include data interpretation, reporting and other activities)
  - 58 sampling events, 5 locations, hot and cold water, 7am, 12pm, 3pm

2014, building plumbing renovated with new PEX, trunk and branch design; low flow fixtures

Drinking water source:
Public water system: Groundwater, treated with free chlorine residual and a corrosion inhibitor, PVC and Iron water mains
OBJ. 1: LITERATURE, PARTNERS, WORKSHOP

- Water Demand, Flow and Use
- Temperature
- Chemical and Microbial Contaminant Concentrations

OBJ. 2A: FIELD MEASUREMENTS

- Pipe Network Design - pipe sizes, layout, fixtures
- Water Quality Parameters
  - Water pH
  - Alkalinity
  - NOM
  - Disinfectant
  - Larson Index
  - Metal Content

OBJ. 2B: EPANET-MSX

- Integrative Hydraulic-Water Quality Models

- Water Age – Stagnation time/Residence Time
- Water Quality at each fixture
- Water Treatment Process
  - Model
  - Calibration
  - Rate Constants
  - Pilot Study
  - Field Study

- Bench Scale Experiment
- Model Benchmark/ Validation

- Input
- Output

OBJ. 3A: RISK ASSESSMENT MODELS

- What are the human health risk associated with the measured and predicted contaminant concentrations?
- Which factors (inputs) significantly influence water quality?

OBJ. 2C: WATER QUALITY MODELS

- Which factors (inputs) significantly influence water quality?
- Which factors (inputs) significantly influence water quality?

OBJ. 3B: DECISION SUPPORT TOOL
Office Building Water Safety:

The Role of Weekend Stagnation

ELIZABETH MONTAGNINO
NOVEMBER 12, 2020
Stagnation of water in office buildings

Friday → Saturday → Sunday → Monday: Low to no water use

Stagnation can induce:

- disinfectant decay\(^1,2,3\)
- metal leaching from plumbing and scales\(^4,5,6\)
- bacterial growth and emergence of pathogens into bulk water\(^3,7,8\)

Flushing has been previously assumed to be adequate for remediating water quality problems.

Technical approach: Fixture use, water sampling, and analysis

3 weekends in Winter 2020
  Friday @ 5:30 pm
  Monday @ 6:30 am

Daily fixture use recorded by building inhabitants

Collected water samples at the point-of-entry and worked our way from the basement to the top floor

**On-Site**
- pH
- Temperature
- Total chlorine

**Lab Analysis**
- Alkalinity
- ICP-OES
- Ion chromatography (IC)
- Flow cytometry for TCC
- Organic carbon: TOC and DOC
- qPCR at Tulane
Service Line and Building Distribution

- Service line: 31.5 G (118.5 L)
  - 3 pipe segments: 25 ft galvanized pipe + two copper pipes, 19.5 ft and 72.5 ft
- A 3-story copper pipe distribution system with 3 risers
- Water softener: 16 G (59.7 L)
- 1 Point of Entry (POE) + 17 Water use locations total
  - 11 sample locations + 1 sample at POE
  - 5 potable cold (C) water sample locations
  - 6 thermal mixing valve (TMV) fixtures
- Appliances
  - On demand water heaters
  - Dishwasher, ice machine, refrigerator
  - Water cooler

Public Water System (PWS) water main with chloramines residual
Results: Fixture use

Week of 1/13/20  Week of 1/20/20
Week of 1/27/20  Week of 2/3/20

Number of times used

Riser 3

Basement
First Floor
Second Floor
Location 3: Left Sink
Bathroom Sink Near Location 7
Not sampled
Disinfectant levels were always lower on Monday; bacteria levels always higher.

Indiana requires 0.2 mg/L as Cl\(_2\) in the PWS distribution system.
Copper consistently exceeded the health-based 1.3 mg/L limit at select locations.

<table>
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<tr>
<th>Location Description</th>
<th>Cu, mg/L</th>
<th>Pb, μg/L</th>
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<tr>
<td></td>
<td>Friday</td>
<td>Monday</td>
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<tr>
<td><strong>POE</strong></td>
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<tr>
<td>1</td>
<td>0.05 - 0.96</td>
<td>0.19 - 0.29</td>
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<tr>
<td><strong>Basement</strong></td>
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<tr>
<td>2</td>
<td>0.87 - 1.5</td>
<td>1.1 - 1.4</td>
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<td>3</td>
<td>0.80 - 1.6</td>
<td>1.1 - 1.3</td>
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<tr>
<td>4</td>
<td>0.74 - 1.9</td>
<td>1.4 - 1.7</td>
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<td><strong>First Floor</strong></td>
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<td>5</td>
<td>0.39 - 0.87</td>
<td>0.68 - 0.78</td>
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<tr>
<td>6</td>
<td>0.49 - 0.69</td>
<td>1.3 - 1.4</td>
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<tr>
<td>7</td>
<td>0.37 - 0.96</td>
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<td>8</td>
<td>0.26 - 0.49</td>
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<td>9</td>
<td>0.43 - 0.47</td>
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<td>10</td>
<td>0.33 - 0.55</td>
<td>0.43 - 0.49</td>
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<td><strong>Second Floor</strong></td>
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<tr>
<td>11</td>
<td>0.53 - 0.93</td>
<td>0.74 - 0.92</td>
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<tr>
<td>12</td>
<td>0.04 - 0.87</td>
<td>0.68 - 0.77</td>
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</tbody>
</table>

Exceedances found every week at Riser 3.

Overall, greater amounts of Cu and Pb were found on Monday morning ($p<0.05$).

Pb always $>1$. 
Flushed reduced copper levels and increased disinfectant levels, BUT rebounded quickly

Flushing Time:
- 9 min. to reach the point-of-entry (POE), $Q = 2.18 \text{ L/min}$
- 54 min. to reach the water main

Copper rebounded at 0.06 mg/L-hr
- Time for copper to exceed 1.3 mg/L: initial conc. 0.09 mg/L... 19 hours

Chlorine decayed at 0.31 mg/L-hr
- Time for chlorine to be <0.2 mg/L: initial conc. 0.4 mg/L... 1 hour
- Time for chlorine to be <0.01 mg/L: initial conc. 0.4 mg/L... 31 hours
Discussion and Recommendations

PWS water met federal and state drinking water standards

10 years after the green building was placed into service, Cu problems were consistently found at 1 of 3 risers due to weekend stagnation

Monday AM had higher TCC, Cu, and Pb levels compared to Friday PM

Cu levels rebounded quickly after fixture flushing. Est. within 21 hours, >1.3 mg/L Total Cl₂ residual decays to below state regulated levels (0.2 mg/L) within Est. 1 hour

Recommendations

As part of a new building’s certificate of occupancy attainment….

Water safety testing for copper, lead, and chlorine should be required to identify conditions where unsafe water may exist in buildings. Weekend stagnation is recommended before sampling.

A plumbing flushing plan and as-built plumbing drawing should be present. This can help the health department, building officials, and building owners understand how the system is designed and may operate.
Thank you.

Elizabeth Montagnino
Purdue University
Lyles School of Civil Engineering

Contact:
emontagn@purdue.edu
Contributions by

Graduate Students
Kyungyeon Ra
Yoorae Noh
Tolulope Odimayomi
Christian Ley
Sruthi Dasika

Undergraduate Research Assistants
Ethan Edwards
Danielle Angert
Conner Poort
Garrett Bryak
Yifei Bi

Caitlin Proctor, Ph.D.
Andrew Whelton, Ph.D.
Tiong Gim Aw, Ph.D. (Tulane University)

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Ross Graduate Fellowship
Andrews Graduate Fellowship
Lilian Gilbreth Postdoctoral Fellowship
Water microbiology of a school building during Summer and Fall seasons

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Study objectives

• This study was conducted to better understand microbial water quality changes in a LEED-certified school building (Green building) during low water use (Summer) and normal water use (Autumn).

Objectives:

• Determine chemical and microbiological water quality at 20 cold and hot water locations in a building;

• Examine occurrence and density of four opportunistic pathogens (*Legionella, Mycobacterium, Naegleria fowleri, Acanthamoeba*) in plumbing of a green school building; and

• Determine if water quality differed between low water use and normal water use conditions.
Field Study: LEED Middle School

- LEED middle school receives chloraminated water from a public water system; Copper plumbing, water softener, hot water recirculation system.
- School water source: blending waters that originate from two different treatment plants (on average, 75% of groundwater source and 25% of surface water source)
- Water samples were collected from 20 different locations. Water sampling schedule:
11,12. **B2C, B2H**: E207J [H119] P-6 Farthest bathroom sink to utility room (cold and hot)

13,14. **SKC, SKH**: F102 [G102] Students’ kitchen (cold and hot)

15,16. **TKC, TKH**: B102A [D110] P-10 Teachers’ Kitchen sink (cold and hot)

9,10. **SH1, SH2**: P-14, P-13 disabled, combined stand Showers (cold)

7,8. **B1C, B1H**: A306R [L123] Closest bathroom sink to utility room (cold and hot)

17,18. **B3C, B3H**: C124B [A132] P-6 bathroom sink (cold and hot)

19,20. **WF1, WF2**: C124B [A132] P-11, P-12 Water Fountains higher, lower (cold)

1. **SL**: Service line (cold)
2. **AS**: After softener (cold)
3. **BWH**: Before water heater (warm?)
4,5. **HWRa, HWRb**: Hot Water Recirculation (120, 140)
6. **AWH**: After water heater (hot)

**UTILITY ROOM**

NOT SHOWN

21,22. Trip Blank, Field Blank
Methods for the pathogen detection

1 liter of tap water was collected (first-draw)

Membrane filtration


**Quantitative PCR** –

- *Legionella* spp. (23S rRNA)
- *Legionella pneumophila* (*mip* gene)
- *Mycobacterium* spp. (the internal transcribed spacer sequence)
- *Mycobacterium avium* (16S rRNA)
- *Naegleria fowleri*
- *Acanthamoeba* spp.
Water quality measurement of first draw samples

| Parameter | Summer | | | Fall | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | After meter (n = 3) | Cold lines (n = 27) | Hot lines (n = 27) | After meter (n = 3) | Cold lines (n = 27) | Hot lines (n = 27) | | |
| **Min** | **x̄** | **Max** | **Min** | **x̄** | **Max** | **Min** | **x̄** | **Max** | **Min** | **x̄** | **Max** |
| **General** | | | | | | | | | | | | |
| Temp, °C | 25.2 | 26.1 | 27.3 | 15.8 | 21.9 | 26.4 | 21.5 | 29.3 | 47.3 | 20.4 | 24.2 | 27.1 |
| pH | 7.6 | 7.8 | 7.9 | 7.2 | 7.8 | 8.5 | 7.7 | 8 | 8.2 | 7.7 | 7.8 | 7.9 |
| DO, mg L⁻¹ | 8.9 | 9 | 9.1 | 2.6 | 6.9 | 10.2 | 3.1 | 5.6 | 8.9 | 7.4 | 8.4 | 9.2 |
| Total Cl₂, mg L⁻¹ | 0.1 | 0.2 | 0.2 | 0 | 0.1 | 1 | 0 | 0.1 | 0.1 | 0 | 0.1 | 0.1 |
| NH₃, mg L⁻¹ | 0.1 | 0.2 | 0.2 | 0.08 | 0.5 | 0.5 | 0.4 | 0 | 0.1 | 0.1 | 0 | 0.1 |
| NH₄⁺, mg L⁻¹ | 0 | 0.2 | 0.48 | 0 | 0.1 | 0.41 | 0.01 | 0.2 | 0.84 | 0.01 | 0.2 | 0.6 |
| Organics | | | | | | | | | | | | |
| TOC, mg L⁻¹ | 1.7 | 1.9 | 2 | 1.2 | 2.2 | 6.7 | 2.9 | 3.4 | 3.8 | 1.8 | 2 | 2.2 |
| DOC, mg L⁻¹ | 1.7 | 1.9 | 2 | 1.2 | 2.2 | 6.5 | 2.6 | 3.3 | 3.8 | 1.8 | 2 | 2.1 |
| Microbiology | | | | | | | | | | | | |
| HPC, CFU/100 mL | 11 | 148 | 40 | 13 | 12614 | 214000 | 0 | 1284 | 12667 | 18 | 114 | 245 |
| TCC, cell per mL | 3.02 | 20.9 | 35.6 | 4.79 | 23.8 | 62.8 | 54.8 | 81.6 | 116.1 | 5.89 | 80.5 | 43.4 |
| Nitrogen | | | | | | | | | | | | |
| NH₄⁻, mg L⁻¹ | 0.4 | 0.7 | 1.3 | 0.1 | 0.3 | 0.5 | 0.1 | 0.1 | 0.2 | 0.4 | 0.6 | 0.8 |
| NO₂⁻, mg L⁻¹ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.1 | 0.1 |
| NO₃⁻, mg L⁻¹ | 0.8 | 1.5 | 2.8 | 0.8 | 1.9 | 3.0 | 0.9 | 1.3 | 1.7 | 1.2 | 1.4 | 1.5 |
| Metal | | | | | | | | | | | | |
| Cu, µg L⁻¹ | 347 | 415 | 503 | 55 | 1356 | 2440 | 196 | 689 | 1320 | 57 | 68 | 81 |
| Pb, µg L⁻¹ | 0 | 0 | 0 | 18.5 | 22 | 40.9 | 0 | 0 | 0 | 0 | 1.3 | 35.1 |

x = mean; lead was only detected in shower cold water, also detected for second draw (7.79 µg L⁻¹) but not for third draw on the last sampling event.

The detection of *Legionella* using cell culture

- Water samples collected on July 20 and Oct 12 were also analyzed for *Legionella* using culture-based method.
- **July 20** - Colonies of *Legionella* species, as confirmed by qPCR, were recovered from 5 of 20 water samples (25%). The *Legionella pneumophila* specific test for these colonies showed negative. This means that other cultivable *Legionella* species were present in the water systems.
- All isolates were identified as most closely related to *Legionella donaldsonii*.
- **Oct 12** – Cultivable Legionella were not detected in water samples.

<table>
<thead>
<tr>
<th>Sampling site</th>
<th>Site ID</th>
<th><em>Legionella</em> species concentration by culture (CFU/100ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>After softener</td>
<td>AS</td>
<td>5,720</td>
</tr>
<tr>
<td>Before water heater</td>
<td>BWH</td>
<td>4,810</td>
</tr>
<tr>
<td>Hot water recirculation</td>
<td>HWRa</td>
<td>970</td>
</tr>
<tr>
<td>Bathroom hot water</td>
<td>B1H</td>
<td>1,040</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Sampling site</th>
<th>Site ID</th>
<th><em>Legionella</em> species concentration by culture (CFU/swab)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathroom shower</td>
<td>SH2 (swab)</td>
<td>7</td>
</tr>
</tbody>
</table>
## Opportunistic pathogen survey of school water systems using qPCR

<table>
<thead>
<tr>
<th>Target organism</th>
<th>Occurrence rate (%)</th>
<th>Concentration (gene copy no. per 100ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sites (n = 20)</td>
<td>Water samples (n = 120)</td>
</tr>
<tr>
<td><strong>Legionella spp.</strong></td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>Legionella pneumophila</strong></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Mycobacterium spp.</strong></td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>Mycobacterium avium</strong></td>
<td>95</td>
<td>75</td>
</tr>
<tr>
<td><strong>Naegleria fowleri</strong></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Acanthamoeba spp.</strong></td>
<td>70</td>
<td>17.5</td>
</tr>
</tbody>
</table>
Spatial and temporal distribution of *Legionella* spp., *Mycobacterium* spp. in plumbing of a green school building as determined by qPCR
Spatial and temporal distribution of *Mycobacterium avium* in plumbing of a green school building as determined by qPCR
Comparison of average concentrations of pathogen genetic markers in water systems under low vs. normal water use conditions

**Legionella**

![Bar chart showing Legionella gene copies before and during the school year with a significant decrease during school (p<0.0001)]

**Mycobacterium spp.**

![Bar chart showing Mycobacterium gene copies before and during the school year with a significant decrease during school (p<0.0001)]

**M. avium**

![Bar chart showing M. avium gene copies before and during the school year with a significant decrease during school (p=0.0073)]
Significant association between physiochemical properties and opportunistic pathogen genetic markers

Monochloramine and *Mycobacterium spp.*

\[ p = 0.0187 \]

Total Organic Carbon and *Mycobacterium spp.*

\[ p = 0.0230 \]

Total Organic Carbon and *Mycobacterium avium*

\[ p < 0.0001 \]

Free Ammonia and *Mycobacterium avium*

\[ p < 0.0001 \]
Conclusions

• The presence of opportunistic pathogens in premise plumbing can be affected by the frequency of water use in a building.

• The rapid rate of disinfectant loss in green buildings due to high water stagnation needs to be better understood and addressed.

• This study demonstrates the importance of considering potential public health impacts in the design of sustainable water systems in green buildings.
Occurrence of Pathogenic *Legionella* and Amoebae spp. from Source (Groundwater) to Exposure Sites (Taps And Cooling Towers) In a Complex Water System

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Advisor: Joan B. Rose  
Departments of Microbiology and Molecular Genetics; Fisheries and Wildlife  
Michigan State University  
November 12th, 2020
The Research Project Has 3 Main Objectives

• Objective 1: Examine pathogenic *Legionella* species in different types of buildings in two different seasons

• Objective 2: Examine pathogenic *Legionella* species on MSU campus groundwater source to distributed water to cooling towers, a wholistic view of the water system

• Objective 3: Examine the co-occurrence between *Naegleria fowleri*, *Acanthamoeba* spp. and *Legionella* spp.
Sampling Sites and Dates for Objective 1

F August 13th, 2018 and January 15th, 2019

BPS: August 13th, 2018 and January 7th, 2019

M August 13th, 2018 and January 8th, 2019
Sampling Sites and Dates for Objective 1

FH: September 4\textsuperscript{th}, 2018 and January 14\textsuperscript{th}, 2019

ERC: August 27\textsuperscript{th}, 2018 and January 9\textsuperscript{th}, 2019
Sampling sites and Dates for Objectives 2 & 3: Variability from Source to Tap, and Cooling Towers

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>F: N= 15</th>
<th>ERC: N= 9</th>
<th>Cooling tower: N = 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent: N= 6</td>
<td></td>
<td></td>
<td>July 25\textsuperscript{th} &amp; 31\textsuperscript{st}</td>
</tr>
<tr>
<td>Effluent: N= 6</td>
<td></td>
<td></td>
<td>and August 7\textsuperscript{th}, 14\textsuperscript{th} &amp; 21\textsuperscript{st}</td>
</tr>
<tr>
<td>July 15\textsuperscript{th}, 23, &amp; 29\textsuperscript{th}</td>
<td>August 12\textsuperscript{th} &amp; 19\textsuperscript{th}</td>
<td>and August 6\textsuperscript{th}, 13\textsuperscript{th}, &amp; 20\textsuperscript{th}</td>
<td>and September 3\textsuperscript{rd}, 9\textsuperscript{th}, 16\textsuperscript{th} and 23\textsuperscript{rd}</td>
</tr>
</tbody>
</table>
### Monitoring: Water Diagnostics using Droplet Digital Polymerase Chain Reaction (ddPCR)

<table>
<thead>
<tr>
<th>Target Species</th>
<th>Primer/Probe name</th>
<th>Primer/Probe Sequence</th>
<th>Reference</th>
</tr>
</thead>
</table>
| **Legionella species**      | 23SF, 23SR, 23SP probe | 5’-CCCATGAGGCAGCCGGTTGAA-3’  
|                             |                   | 5’-AACATCCAGCAATATTGACGATTAGC-3’  
|                             |                   | 5’-HEX-TCCACACCTGCTATCAAAGTCTGAGT-BHQ1-3’  
| **L. pneumophila (mip gene)** | mipF, mipR, LmipP | 5’-AAAGGCTAGCAAGAGCGCTATG-3’  
|                             |                   | 5’-GAACTTGTGTTAAGAGCGTCTTATTG-3’  
|                             |                   | 5’-FAM- TGGCGGTCAATTTGGCTTTAAAACCGA-BHQ1-3’  
| **L. micdadei**             | Pan-Legionella F, Pan-Legionella R, LmdadeiP, Lanisap, LbozemaniiP, LlongbeachaeP | 5’-GTACTAATTGCGATGTCTTG-3’  
| **L. anisa**                |                   | 5’-TTCATTCTGAGTTCGATG-3’  
| **L. bozemani**             |                   | 5’-FAM- AGCTGTTGTTAATTAGCCCAATCGG-BHQ1-3’  
| **L. longbeachae**          |                   | 5’-HEX-CTCAACCTAAGCGAGACTCTGAGG-BHQ1-3’  
|                             |                   | 5’-FAM-CTACGCCATTCTCAGCAAAACCGAT-BHQ1-3’  
|                             |                   | 5’-HEX-CTGAGTATCCTGGCAAATATGCGCG-BHQ1-3’  
| **Acanthamoeba spp.**       | 18S rRNA, 18S rRNA, 18S rRNA | 5’-CGACACAGCGATTAGGAGGACG-3’  
|                             |                   | 5’-CCGACGCAGCAAGGACGAC-3’  
|                             |                   | 5’-FAM- TGAATACAAAAACACCACCATCGGC-GC-BHQ1-3’  
| **Naegleri fowleri**        | ITSF, ITSR, ITSP  | 5’-GTGAAAAACCTTTTTTTCATTACA-3’  
|                             |                   | 5’-AAATAAAGATGTACGACATTTGAAA-3’  
|                             |                   | 5’-HEX-GTG GCC CAC GAC AGC TTT-BHQ1-3’  

Source: BioRAD
Legionella spp.

- Total samples collected: 37
- *Legionella* species (23S rRNA) in all water samples was 100% positive
- 2 out of 5 buildings potentially amplified at the points of use
  - 1.8 to 3.5 $\log_{10}$ GC/100 mL on influent vs points of use (Winter 2019)
Presence of pathogenic *Legionella* species at the taps & water usage patterns

*Water usage for FH was only available for January*
Legionella species (23S rRNA) in the Cooling Towers, Buildings (ERC & F), and the Reservoir (In. & Ef.)

One-Way ANOVA

CT vs Res_In, Res_EF, Fa_In, Fa_H, Fa_C (p= 0.0156, 0.0003, 0.0006, <0.0001, 0.0001)

ERC_C vs Res_EF, Fa_In, Fa_H, Fa_C (p= 0.0043, 0.0036, 0.0002, 0.0020)

ERC_H vs Res_EF, Fa_In, Fa_H, Fa_C (p= 0.0152, 0.0107, 0.0007, 0.0074)

ERC_In vs Fa_H (p = 0.0091)

* (Outliers)
Principal Component Analysis biplot showing the clustering of the data according to the water sampling sites

^Abundance represents free-living amoebae and *Legionella* species
Legionella spp.

- Total samples collected: 42

- Acanthamoeba spp. (%+)
  - 8/42 (19%)

- Naegleria fowleri (%+)
  - 17/42 (40%)

- Naegleria fowleri correlates with L. micdadei, and L. bozemanii (p= 0.002**, 0.002**) in the BWS
Conclusion

• *Legionella* spp. (23S) and pathogenic *Legionella* related to water usage patterns

• Water age may play a role on the occurrence and concentration of *Legionella* spp. (23S) in the distribution system, premise plumbing, and the cooling towers

• A separation was between water samples collected from the cooling towers (CT) and those collected from the drinking water system (Fa, ERC, and RES_IN, and RES_EF)

• *Legionella micdadei* and *L. bozemanii* were more often related to *Naegleria* than *Acanthamoeba* spp.
Discussion

• Large volume composite sampling was successful in the study of *Legionella* specific species in a complex water system.

• Should compare pathogenic *Legionella* species in the influent vs the points of use.

• More studies are needed to understand the microbial ecology and water chemistry that affects the amplification of *Legionella* and amoebae species.
Building Water Quality Relationships

Ryan Julien*, Jade Mitchell, Pouyan Nejadhashemi, Babak Saravi, Ian Kropp
November 12, 2020
Introduction

• Water quality in premise plumbing is highly variable
• Goal: Reduce the number of input variables required to identify elevated Legionella risks
Data Utilized – Analytical Data

- Analytical results
  - 59 sampling events from 8/17/17 through 10/9/2018
  - Seven fixtures
  - 12 variables including pH, residual chlorine, HPC, and qPCR for Legionella

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Variable Description</th>
<th>Units</th>
<th>2.5%</th>
<th>50.0%</th>
<th>97.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>pH</td>
<td>NA</td>
<td>7.36</td>
<td>8.00</td>
<td>9.04</td>
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<tr>
<td>Temp</td>
<td>Temperature</td>
<td>C</td>
<td>15.63</td>
<td>22.90</td>
<td>26.30</td>
</tr>
<tr>
<td>DO</td>
<td>Dissolved oxygen</td>
<td>mg/L</td>
<td>4.30</td>
<td>8.40</td>
<td>10.56</td>
</tr>
<tr>
<td>Total.Cl</td>
<td>Total Chlorine</td>
<td>mg/L</td>
<td>BDL</td>
<td>0.10</td>
<td>1.00</td>
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<tr>
<td>Free.Cl</td>
<td>Free Chlorine</td>
<td>mg/L</td>
<td>BDL</td>
<td>0.01</td>
<td>0.75</td>
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<tr>
<td>TOC</td>
<td>Total Organic Carbon</td>
<td>mg/L</td>
<td>0.42</td>
<td>0.81</td>
<td>15.36</td>
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<tr>
<td>DOC</td>
<td>Dissolved Organic Carbon</td>
<td>mg/L</td>
<td>0.42</td>
<td>0.73</td>
<td>18.97</td>
</tr>
<tr>
<td>Alka</td>
<td>Alkalinity</td>
<td>mg/L as CaCO₃</td>
<td>264.15</td>
<td>287.25</td>
<td>332.65</td>
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<tr>
<td>TTHM</td>
<td>Total Trihalomethanes</td>
<td>mg/L</td>
<td>0.05</td>
<td>15.57</td>
<td>31.55</td>
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<tr>
<td>TCC</td>
<td>Total Cell Count</td>
<td>#cells/mL</td>
<td>1.54E+03</td>
<td>3.77E+04</td>
<td>1.56E+06</td>
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<tr>
<td>HPC</td>
<td>Heterotrophic Plate Count (by culture)</td>
<td>CFU/100mL</td>
<td>4.03E+00</td>
<td>1.01E+04</td>
<td>3.60E+07</td>
</tr>
<tr>
<td>Leg.sp</td>
<td>Legionella spp. (by qPCR)</td>
<td># gene copies /100mL</td>
<td>2.29E+01</td>
<td>4.02E+03</td>
<td>1.78E+05</td>
</tr>
</tbody>
</table>
Data Utilized – Water Use Metrics

- Water use records (two-week span prior to sample collection)
  - Mean time since last event (meanTSL)
  - Maximum time since last event (maxTSL)
- Number of events (num.events)
- Event volume (vol.events)

<table>
<thead>
<tr>
<th>Fixture Name</th>
<th>ID tag</th>
<th>Design Flowrate (LPM)</th>
<th>Total Volume Consumed (m³)</th>
<th>Percent of Cumulative Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Line</td>
<td>SL</td>
<td>NA</td>
<td>130.7</td>
<td>100%</td>
</tr>
<tr>
<td>Kitchen Sink - Cold</td>
<td>CKS</td>
<td>6.8</td>
<td>5.9</td>
<td>4%</td>
</tr>
<tr>
<td>Bathroom Sink - Cold</td>
<td>CBS</td>
<td>4.5</td>
<td>2.0</td>
<td>2%</td>
</tr>
<tr>
<td>Water Heater</td>
<td>WH</td>
<td>NA</td>
<td>40.6</td>
<td>31%</td>
</tr>
<tr>
<td>Kitchen Sink - Hot</td>
<td>HKS</td>
<td>6.8</td>
<td>5.2</td>
<td>4%</td>
</tr>
<tr>
<td>Bathroom Sink - Hot</td>
<td>HBS</td>
<td>4.5</td>
<td>16.2</td>
<td>12%</td>
</tr>
<tr>
<td>Bathroom Shower - Mixed</td>
<td>MBS</td>
<td>7.6</td>
<td>36.6</td>
<td>28%</td>
</tr>
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Analyses Conducted

- Correlation Analysis
  - Spearman correlation coefficients (non-parametric)
- Principal Component Analysis (PCA)
- Generalized Linear Model (GLM)
  - Linear modeling to predict Legionella concentrations
  - Multiple iterations considered to account for missing observations
- Bayesian Variable Selection
# Spearman Correlation Coefficients

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<th>pH</th>
<th>Temp</th>
<th>DO</th>
<th>Total.Cl</th>
<th>Free.Cl</th>
<th>TOC</th>
<th>DOC</th>
<th>Alka</th>
<th>TTHM</th>
<th>TCC</th>
<th>HPC</th>
<th>Leg.sp</th>
<th>vol.events</th>
<th>num.events</th>
<th>meanTSL</th>
<th>maxTSL</th>
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<td>1.00</td>
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</tr>
<tr>
<td>Temp</td>
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<td>1.00</td>
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<tr>
<td>DO</td>
<td>-0.30</td>
<td>-0.40</td>
<td>1.00</td>
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<td></td>
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<tr>
<td>Total.Cl</td>
<td>-0.20</td>
<td>-0.51</td>
<td>0.27</td>
<td>1.00</td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Free.Cl</td>
<td>-0.19</td>
<td>-0.41</td>
<td>0.22</td>
<td>0.79</td>
<td>1.00</td>
<td></td>
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Principal Component Analysis

- Twelve variables
  - Free.Cl and DOC not considered due to strong correlations with other variables
- Principal Components
  - PC1 – Water age
    - 39% of variance
  - PC2 – Biofilm detachment
    - 14% of variance
  - PC3 – Biofilm development/age
    - 9% of variance
Generalized Linear Model

• Preliminary GLM
  • Eliminated alkalinity, allowed more data to be considered
• GLM with all variables
  • All combinations of main-effects evaluated with $\Delta AIC_C$
• Two models evaluated
  • m.top <- top performing model
  • m.comp <- Uses all variables found in models with $< 2.0 \Delta AIC_C$
  • Random effect included for sample location

• m.top
  • DO, HPC, maxTSL, meanTSL, num.events, pH, TCC, TOC, Total.Cl, and Location

• m.comp
  • DO, HPC, maxTSL, meanTSL, num.events, pH, TCC, TOC, Total.Cl, Location, and $TTHM$
GLM Results

- Models exhibited similar performance
  - Only difference is TTHM

- Variable significance
  - DO, HPC, TCC (***) in both
  - TOC (*** in m.top, (**) in m.comp

- Water age metrics
  - Only meanTSL significant (*)
  - Demonstrates need for accurate water age measurement

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Significance:
- *** < 0.005
- ** < 0.01
- * < 0.05
Bayesian Generalized Linear Model

- Employed BGLR library in R
  - Relies on Gibbs sampling with scalar updates
  - Assumes priors based on Gaussian “point and slab” mixtures
  - BGLR used for variable selection in high-dimensional data sets

- Results
  - High probability (98%-100%) of non-zero parameter estimate for meanTSL (stagnation)
  - Low probability (14%-38%) of non-zero maxTSL parameter
  - All others 52%-57%

- Data appear too correlated to overcome point mass in prior
  - However, water age/stagnation highlighted as important
Conclusions

• Results agree with published literature
  • Confirms these phenomena occur at full-scale
  • Legionella more prevalent with elevated DO, HPC, TCC, TOC, and water age

• Additional research is needed
  • Developing water age model for premise plumbing
Thank You & Questions

Contact us:
Jade Mitchell, PhD jade@msu.edu
Ryan Julien, PE julienry@msu.edu
BOOTSTRAP AGGREGATED DECISION TREE CLASSIFICATION OF END-USE EVENTS THROUGH UPSTREAM FEATURES

Ian Kropp \textsuperscript{a,b}, A. Pouyan Nejadhashemi \textsuperscript{a,*}, Ryan Julien \textsuperscript{a}, Jade Mitchell \textsuperscript{a}, Andrew J. Whelton \textsuperscript{c}

\textsuperscript{a} Department of Biosystems and Agricultural Engineering, Michigan State University, East Lansing, Michigan, United States
\textsuperscript{b} Department of Computer Science and Engineering, Michigan State University, East Lansing, Michigan, United States
\textsuperscript{c} DLyles School of Civil Engineering, Department of Environmental and Ecological Engineering, Purdue University, West Lafayette, Indiana, United States
Understanding water end-use is critical to:

- designing premise plumbing guidelines
- forecasting water demand
- projecting the impacts of water saving practices and devices
- determining water age

However, end-use sensor systems are costly (on the order of $100K) to install for a single home.
• Reducing the cost of analyzing house end-use events would open end-use research to a wider group of practitioners

• Machine learning is an effective way to classify end-use events with an affordable number of sensors
RESEARCH QUESTIONS

• Can end-use events be categorized by a few upstream sensors in a system?
• What upstream sensors and preprocessing methods are optimal for use in a machine learning system?

Hypotheses

We hypothesized that an affordably small number sensors will be sufficient to predicting end-use events via a machine learning model.
We exhaustively trained and tested a machine learning algorithm (bootstrap aggregated decision trees) to classify…

- sink, shower, dishwasher, and washing machine events

… for all combinations of …

- upstream sensors
- preprocessing methods

… using real world data from the ReNEWW house.

We then analyzed the best of these above configurations, and analyzed the best sensors and preprocessing methods with respects to:

- accuracy
- overfitting
EXAMPLE OF PREPROCESSING

- Amplitude
- Duration
- Maximum slope

First principal component of selected features
Main Findings

- Lower error
- Lower overfitting

Graph showing a scatter plot with total testing error (%) on the y-axis and total training error (%) on the x-axis. The graph highlights lower error and lower overfitting with specific data points and color coding for worst training error among categories.
MAIN FINDINGS: PERFORMANCE AMONG CATEGORIES
DISCUSSION

- Our algorithm was able to accurately predict all categories, though washing machine was moderately overfitted
- Best sensors for machine learning:
  - The city main volumetric flow sensor
  - The city hot water inlet volumetric flow sensor
- The best preprocessing methods for machine learning were:
  - Event duration
  - Maximum slope of event hydrograph
RECOMMENDATIONS

- Two to four sensors were optimal for minimizing error and overfitting
- The methodology is expandable to other:
  - premise plumbing systems
  - available sensors
  - preprocess methods
  - machine learning algorithm
QUESTIONS
Development of Integrated Hydraulic Water Quality Models

Maria Palmegiani, Juneseok Lee, Jade Mitchell, Amirpouyan Nejadhashemi, Andrew J. Whelton
**Retrofit Net-Zero Energy, Water and Waste House**

http://www.ReNEWWhouse.com

Area: 266 m$^2$, 4 bedrooms, 1.5 baths
30,000+ water quality measurements
2.64 billion online plumbing measurements

- Thermocouples
- Indoor air temperature
- Flowrates/fixture
- Energy use/device

1x/second

EPANET 2.2 Input File
**COLD Water System**

EPANET 2.2 Input File
**HOT Water System**
Multi-species calibration Models

Input:
- Water Demand Flow / Use
- Pipe Network Design
- Temperature/ pH (Assumed Constant within each season)
- Water Quality Parameters
- Chemical/ Microbial Contaminant Concentrations
- EPANET 2.2 input file
- EPANET-MSX file

Output:
- Integrative Hydraulic Water Quality Models
- Time-series based water quality prediction at each fixture

Calibrations:
- 540 x n Scenarios

Input:
- 4 Seasons (Summer, Fall, Winter, Spring)
- “n” Water quality at service line
- 15 Pressure boundary conditions (10 psig, 15 psig, 20 psig,...,80 psig)
- 9 Conservation Scenarios (5%, 10%, 15%,..., 50%)

Water Quality Parameters:
- HPC
- Free Chlorine
- TTHM
- NO₃
- NO₂
- NH₃
- DOC
- Heavy Metals
Multi-species calibration models—governing equations

\[ \frac{dC}{dt} = -KC \]
Where,
\( k \) = Free Chlorine reaction rate constant
\( C \) = Chlorine concentration

\[ \frac{\partial C_{TTHM}}{\partial t} = k(C_{TTHMMAX} - C_{TTHM}) \]
Where,
\( k \) = TTHM reaction rate constant
\( C_{TTHMMAX} \) = Maximum TTHM concentration
\( C_{TTHM} \) = TTHM concentration

\[ \frac{dX_h}{dt} = Y_h \left( q_m \left[ \frac{BOM}{k_s + BOM} \right] \right) X_h - k_d \[ HOCl \]
Where,
\( X_h \) = heterotrophic biomass concentration
\( BOM \) = biodegradable organic matter
\( k_s \) = half maximum rate concentration
\( y_h \) = synthesis yield
\( q_m \) = max specific rate of utilization

Woolschlager et al., 2007
Seyoum & Tanyimboh, 2017
Tiruneh et al., 2016
Multi-species calibration models

Accounts for temperature/ pH variations by assuming constant/ season
Split into smaller clusters to match the water sampling trip dates

1. Kitchen Sink
2. Bath 2 Sink
3. Bath 2 Shower

1. Cold Water System
2. Hot Water System

1. Fall 1 (10/10/2017-10/16/2017)
5. Fall 2 (9/20/2018-10/9/2018) (VAL)

1-minute timestep ≈ 53,000 data points/ Month
\[ \frac{\partial C_{TTHM}}{\partial t} = K_{TTHM1} - K_{TTHM2} \cdot TTHM \]

\[ K_{Universal1} = 1.5 \quad \text{and} \quad K_{Universal2} = 0.04 \]

**Kitchen Sink**
- \( K_1 = 6.0 \)
- \( K_2 = 1.0 \)

**Bath 2 Sink**
- \( K_1 = 0.6 \)
- \( K_2 = 1.2 \)

**Bath 2 Shower**
- \( K_1 = 2.0 \)
- \( K_2 = 1.1 \)
HPC (CFU/L)

\[
\frac{d\text{HPC}}{dt} = K_{HPC1} \cdot \text{HPC} - K_{HPC2} \cdot \text{FCL}
\]

\[
K_{\text{Universal}1} = 0.01 \quad K_{\text{Universal}2} = 0.01
\]

**Kitchen Sink**

\[K_1 = 0.01\]
\[K_2 = 0.01\]

**Bath 2 Sink**

\[K_1 = 0.001\]
\[K_2 = 0.09\]
Free Chlorine (mg/L)

\[ \frac{dC}{dt} = K_{FCL} \cdot FCL \quad K_{Universal} = 0.2 \]

Kitchen Sink  
\( K = 35 \)

Bath 2 Sink  
\( K = 0.008 \)

Bath 2 Shower  
\( K = 18 \)
Limitations

Better sensors needed
Availability of governing equations
Grab vs. online sensors

Thank you & Questions?

• Maria Palmegiani, mpalmegi@purdue.edu
• Juneseok Lee, Juneseok.Lee@manhattan.edu
Comparing Risks Across Building Water Use Types with QMRA

Ryan Julien*, Jade Mitchell, Md. Rasheduzzaman, Wanyu Huang, Yolanda Brooks, Patrick Gurian, & Mark Weir
November 12, 2020
Outline

- Introduction
- Model
- Results
- Conclusions

Image: QMRA Wiki (qmrawiki.canr.msu.edu/)
Introduction

• Goal: Assess differences in pathogen health risk across common water use types

• Pathogens
  • Mycobacterium Avium complex (MAC)
  • Legionella spp.

• Hospital/group home setting
  • Higher-risk population
  • Pathogen concentrations from studies in these homes

• QMRA Framework

• Water uses considered:
  • Showering
    • Conventional (13 LPM)
    • Low-flow (7 LPM)
  • Toilet Flushing
    • Flushometer (FOM)
    • Pressure-assisted (PAT)
    • High-efficiency (HET)
Model Form

• **D<sub>P</sub>** – Exposure dose of each pathogen, P
• **R** – Recovery efficiency
  • 0.84 (Hamilton, 2019)
• **C<sub>P</sub>** – Concentration of pathogen P
  • MAC - Triangular dist. (de Moulin 1988)
  • Legionella - Lognormal dist. (Fillipis 2018)
• **R<sub>B</sub>** – Breathing rate
  • Normal dist. (USEPA, 2011)
• **t** – Exposure duration
  • Shower = 15 min
  • Toilet = 30 min (reflects sampling methods)
• **C<sub>aer,d</sub>** – Concentration of aerosolized droplets of diameter d (in microns)
• **V<sub>d</sub>** – Volume of each aerosol of diameter d
• **η<sub>D,d</sub>** - Deposition efficiency for aerosols of diameter d

\[
D_P = \frac{1}{R} C_P R_B t \sum_d C_{aer,d} V_d \eta_{D,d}
\]

\[
R_P = 1 - e^{-k_P D_P/C}
\]

• **R<sub>P</sub>** – Risk of infection for each pathogen, P
• **k<sub>P</sub>** – Dose-Response parameter
  • (Hamilton et al. 2017)
• **C** – Exposure route conversion factor
  • (Hamilton et al. 2017)
Exposure Pathway

Source Water

Aerosolization

Showers
Low-Flow: 7 L/min
Conventional: 13 L/min

Toilets
High-Efficiency (HET)
Pressure-Assisted (PAT)
Flushometer (FOM)

Inhalation
Pathogen Input Concentrations

- **MAC**
  - Data: de Moulin et al. 1988
  - Triangular distribution based on minimum, median, maximum
  - Hot/cold water simulated separately

- **Legionella**
  - Data: Filipis et al. 2018
  - Fit a log-normal distribution
    - Raw data available
  - Hot and cold water assumed to contain same concentration
Common Correlations within Model

MAC in Low-Flow Shower

- **Breathing Rate**
  - Correlated with dose (0.80) and risk (0.62)

- **Concentration**
  - With dose (0.54) and risk (0.42)

- **Risk**
  - With dose (0.77) and k (0.63)
Results – Showering

- Low-flow showers exhibited slightly lower risk
  - True for both MAC and Legionella
    - Higher flowrate ⇒ more aerosols
  - This analysis does not consider the effects of stagnation
Results – Toilet Flushing

• Risks for toilets
  • FOM > PAT > HET
  • True for both pathogens
  • Differences more pronounced for MAC
Conclusions

- Risks across all water use are low
  - Used dose-response factor for general population
- Additional water use appears to increase risk
  - Effect of stagnation not considered
- Pathogen concentrations highly variable

- Potential improvements
  - Additional data for pathogen concentration estimates
  - Consider water age/stagnation
  - Incorporate dose-response for vulnerable populations
Thank You & Questions

Contact us:
Jade Mitchell, PhD jade@msu.edu
Ryan Julien, PE julienry@msu.edu
Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health

NEXT STEPS

awhelton@purdue.edu
## Overview of Major Activities

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### Obj 1. Water Conservation Trends
- Workshop

### Obj 2. Effect of Flow on Water Quality
- Residential – 1 year chem/micro
- Residential – Pathogen exposure
- Residential – Water Age/HRT
- Residential – Hydraulics
- Residential – Fixture prediction
- Residential – Rainwater switch
- Residential – Integrative Hydro-WQ model
- LEED School Bldg – Chemistry / Microbiology
- LEED School Bldg – Pathogens
- LEED School Bldg – Pathogen exposure
- LEED Univ Bldgs – Chemistry / Microbiology
- LEED Office Bldg – Chemistry / Microbiology
- Experiment – GIP/PEX plumbing
- Experiment – Metal deposition in plumbing
- Experiment – Building plumbing TTHMs
- Experiment – PEX TTHMs and leaching
- Experiment – Chem/Microbiology
- Int. Hydro–Fate WDS/Prem Model
- Risk Models with Building Model

### Obj 3. DST Development
- Development
- Workshop
- Upgrade
Remaining Efforts

Integrative Hydraulic Water Quality Model for the Residential Home (EPANET)

Conduct Water Quality Modeling and Risk Analysis

Develop Decision Support Tool (DST)

Finish Studies
- Pathogens in Schools
- Office Building Water Quality
- Copper in Schools
- Institutional Building Microbiology
- Downstream fixture prediction

Inform and Receive Feedback from Partners

Consider Feedback in DST and Deploy

Deliver
The Pending Decision Support Tool

Development of Decision Support Tool (DST) will be performed by the Decision Support and Informatics (DSI) Unit at Michigan State University.

We draw from multiple data sources including:

- Water distribution (Partners-Whelton)
- Premise plumbing modeling (Obj. 2b-Lee)
- Water quality modeling (Obj. 2c-Mitchell)
- Risk assessment (Obj. 3a-Mitchell)

To address different issues such as:
- Right-sizing (Lee/Palmegiani)
- The effect of plumbing designs (Lee/Palmegiani)
- Stagnation times (Mitchell/Julien)

on water quality and human health risks within a robust information platform
Status on the Decision Support Tool

• A private and secure data repository is established for all collaborators
• Created wireframes for a future decision support tool
• A SQL database was established which hosts the results from different sources, including:
  • Modeling exercises
  • Partner inputs
• We have designed and implemented a powerful API to interface between the database and the decision support tool

Initial Plan for Disseminating the Results to Public after the Grants End

The DST website will be published in the Decision Support and Informatics website (dsiweb.cse.msu.edu) and advertised through different means such as:
• University newsletters
• Conference presentations
• The Whirlpool ReNEWW house website
• Trade conferences and associations
• Standard and trade organizations (e.g., NIST, IAPMO, ASPE)
Right Sizing Tomorrow's Water Systems for Efficiency, Sustainability, & Public Health

Next Steps
Andrew Whelton, Jade Mitchell, Joan Rose, Juneseok Lee, Pouyan Nejadhashemi, Erin Dreelin, Tiong Gim Aw, Amisha Shah, Matt Syal, Maryam Salehi

November 2020

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