HOLISTIC ASSESSMENT OF POINT OF USE CARBON FILTERS ON DRINKING WATER SAFETY

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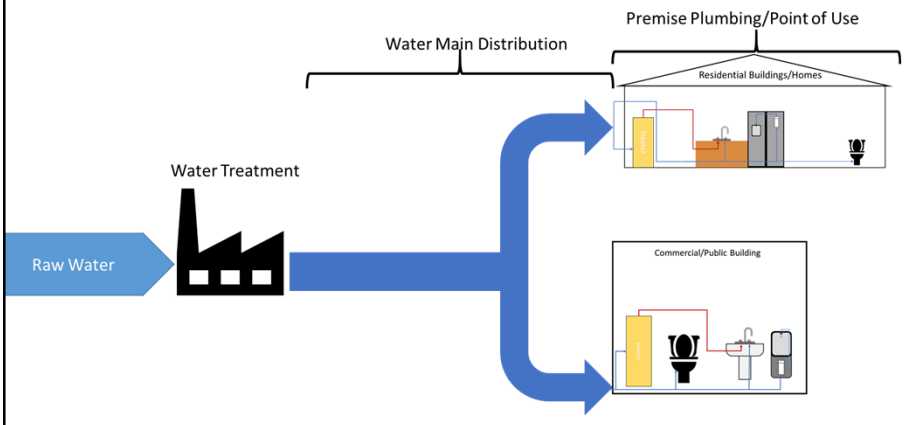
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Public Trust in Public Water Systems

- Public Trust in Public Water Systems Have Decreased
  - Driven by highly publicized water issues
    - Flint Michigan
    - New York Legionnaire's Disease Outbreak
- Distrust in Added Chemicals
  - Distaste in Chlorine
- Lead to Point of Use Treatment/Alterations of Drinking

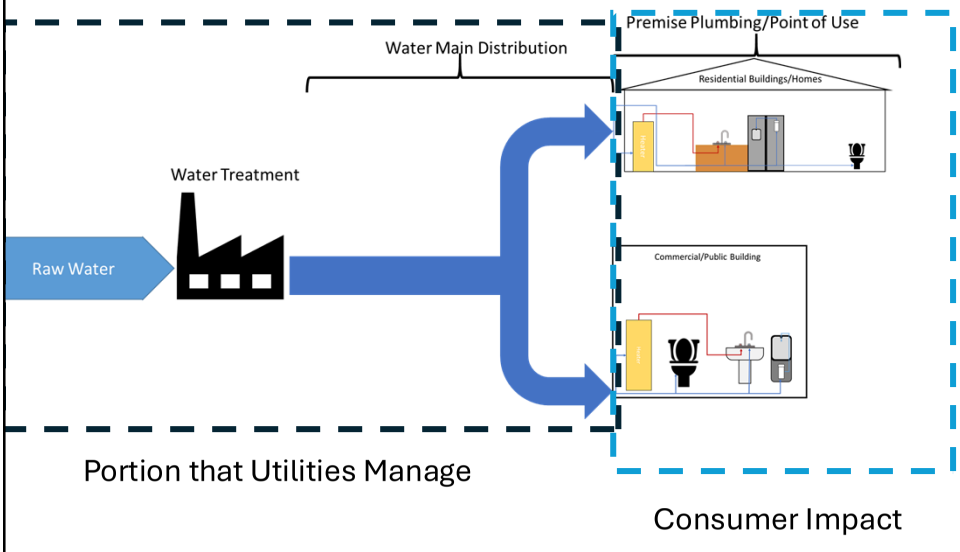
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Public Water Systems



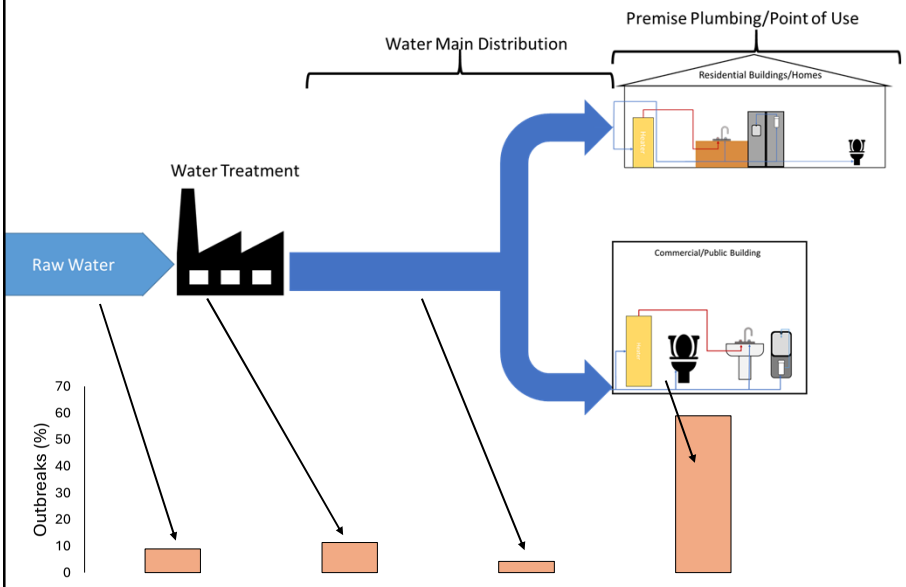
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Public Water Systems



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Public Water Systems



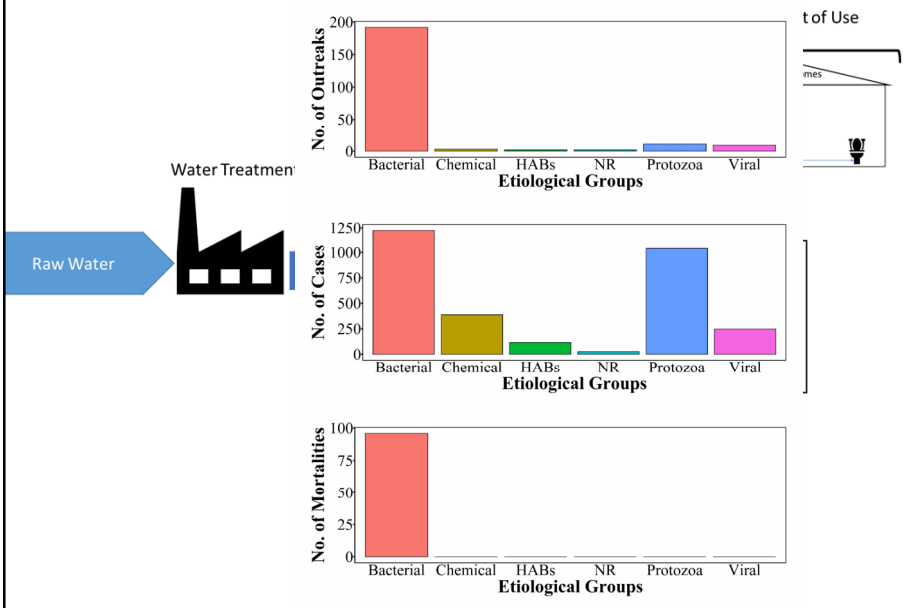
Reported Outbreaks

- Majority of outbreaks are not associated with treatment or distribution
  - Portion managed by municipalities
- Majority associated with premise plumbing

Data from CDC Waterborne Disease Report (Benedict et al. 2017)

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Public Water Systems

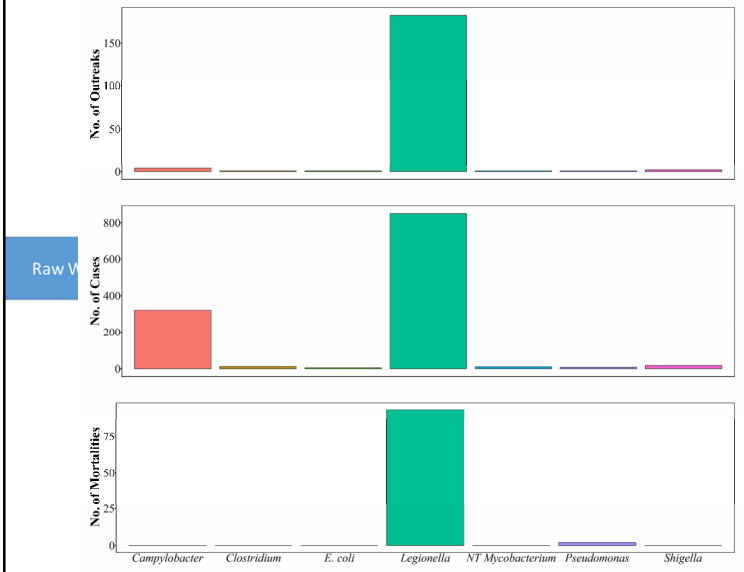


Epidemiology

- Majority of Outbreaks from bacterial causes
- Most Cases caused by Bacteria
  - Significant amount caused by Protozoa
- All known mortalities caused by Bacteria

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Public Water Systems



Raw W

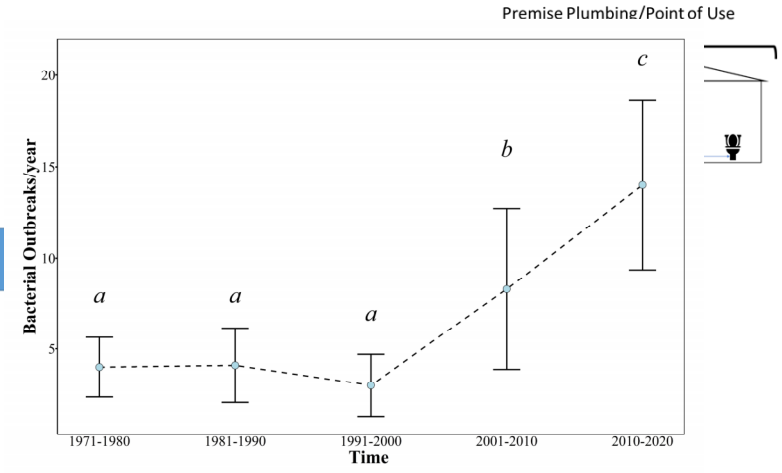
Epidemiology - Bacteria

- With bacteria the major etiology is Legionella
  - Legionella causes pneumonia and legionnaire's disease
- Pseudomonas has caused one drinking water mortality
  - Causes pneumonia
- Represents a significant shift in associated diseases
- Respiratory vs GI
- Opportunistic Pathogens (OPs)

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Public Water Systems

Raw Water

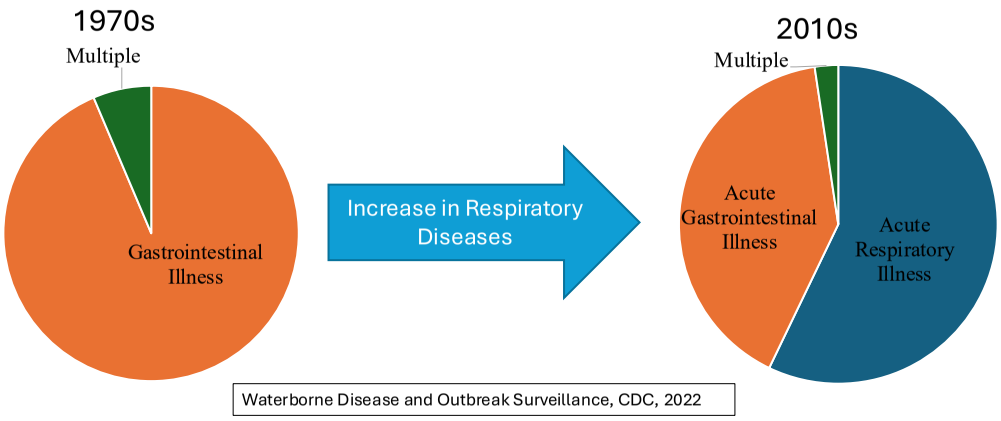


Reported Outbreaks

- Majority of outbreaks are not associated with treatment or distribution
  - Portion managed by municipalities
- Majority associated with premise plumbing
- Bacterial etiology has increased significantly over the last several decades

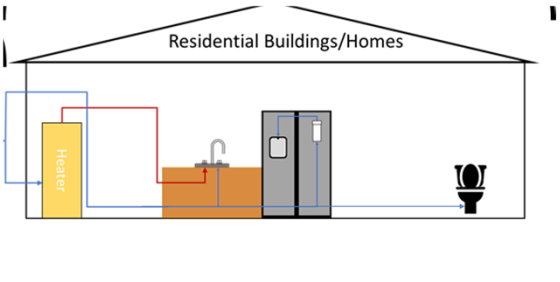
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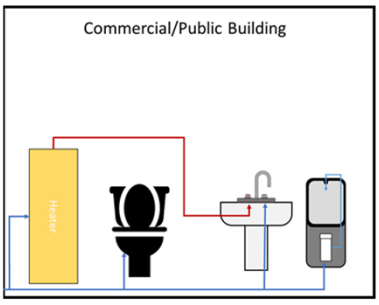
Public Water Systems



Waterborne Disease and Outbreak Surveillance, CDC, 2022

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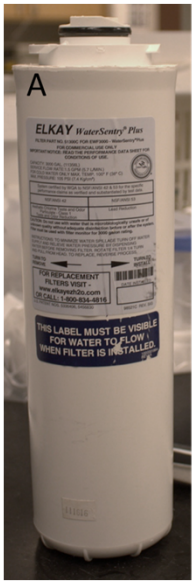




Study Motivations

- Premise Plumbing is Most Vulnerable Area for Pathogen Growth
- Premise Plumbing is Well Studied
  - Stagnation leads to significant water quality changes (Bedard et al., 2018)
  - This Leads to significant potential pathogen growth (Swanson et al., 2021)
- Point of Use Treatment Systems are Not Well Studied
  - Most Popular is Carbon Block Filters

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Study Motivations

- Common in Many Appliances
  - Refrigerators
  - Water Fountains
- Porous Carbon Block Used to Improve Cosmetic Quality
  - Chlorine Disinfectant
- Impact on Microbiological Water Quality is not Well Studied

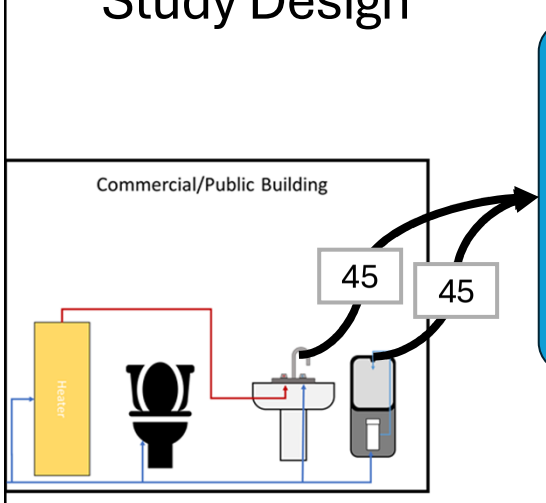
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University of Idaho
College of Engineering

STUDY DESIGN

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Study Design



1L Water Sample

Monitored For:

- General Water Quality
  - pH, TDS, Temp.
  - Chlorine
- Heavy Metals
  - Primary: Cu, Cd, Pb
  - Secondary: Fe, Ni, Zn
  - Contaminant Candidate List (CCL): Al, Co, Mn
- Microbial Risks
  - CCL Pathogens:
    - *Legionella*
    - *Mycobacterium*
    - *Pseudomonas*
  - Emerging OPs:
    - *Acinetobacter baumannii*
    - *Aeromonas hydrophila*
    - *Methylobacterium mesophilicum*
    - *Stenotrophomonas maltophilia*

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1L Water Sample

General Water Quality
- Nutrients – DOC/TN
- Chlorine Residual (DPD)

Heavy Metals
- ICP-MS
- Total Metals

Heterotrophic Plate Counts
- Incubated 48hrs @ 37C
- Quantified as CFU/100mL

Biomass Isolation

DNA Extraction 16S rRNA PCR

MiSeq Sequencing



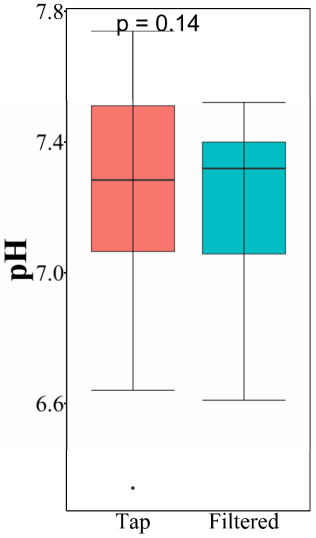
Microbiome Profiles

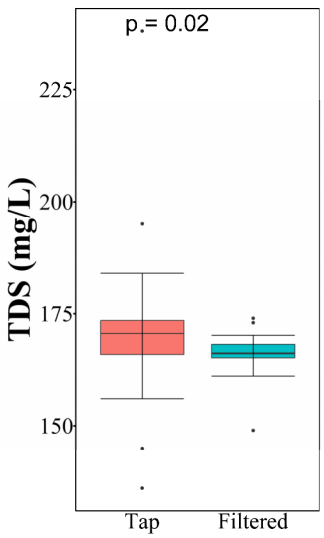
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HOW DO POU FILTERS IMPACT WATER QUALITY

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Water Quality - General



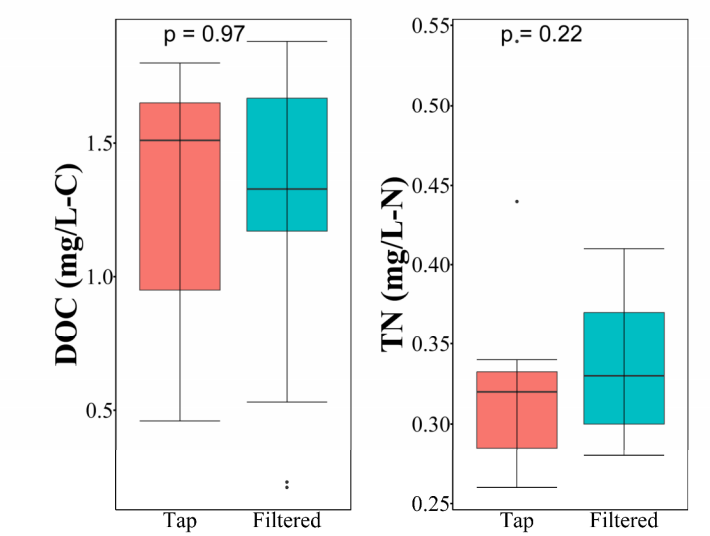


Impact of Filters

- No change in pH
- A slight reduction in TDS

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DOC and TN

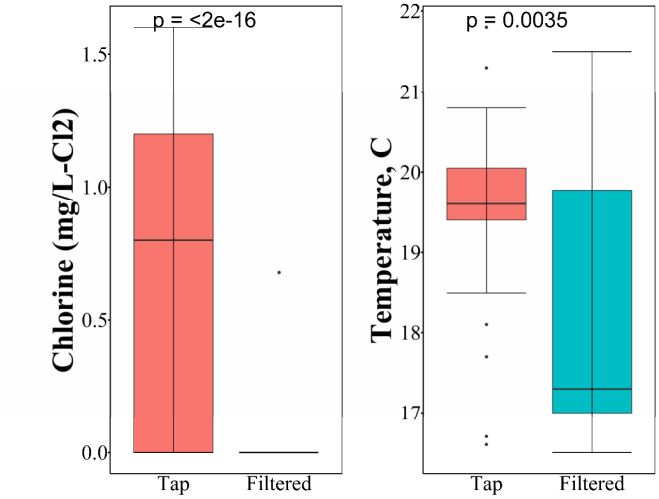


Impact of Filters

- No change in pH
- A slight reduction in TDS
- No impact on DOC/TN

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Chlorine and Temperature



Impact of Filters

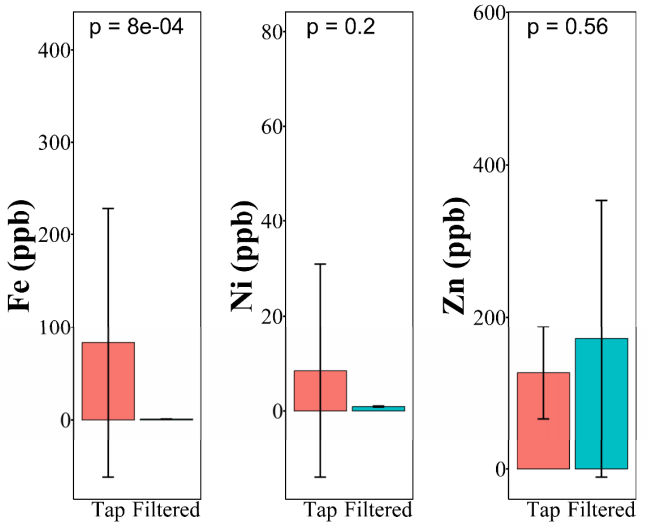
- No change in pH
- A slight reduction in TDS
- No impact on DOC/TN
- Complete Reduction in Chlorine Residual
  - Could lead to microbial growth
- Slight reduction in temperature
  - Some are refrigerated.

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HOW DO POU FILTERS IMPACT HEAVY METAL EXPOSURE?

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Heavy Metals - Secondary

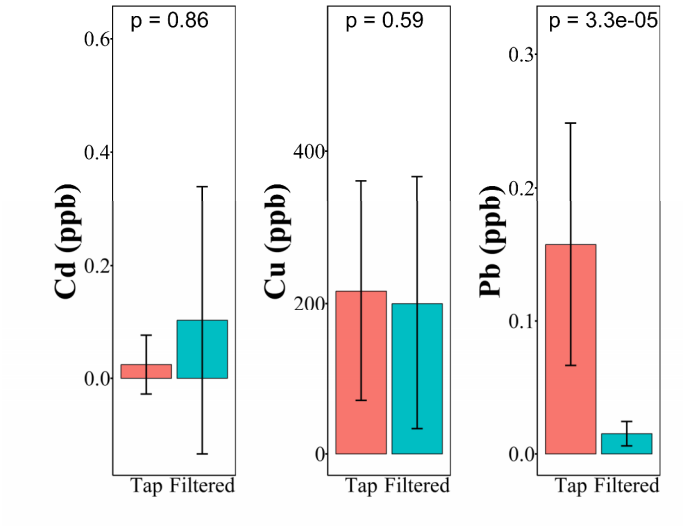


Impact of Filters - HM

- A significant reduction in Iron

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Heavy Metals - Primary

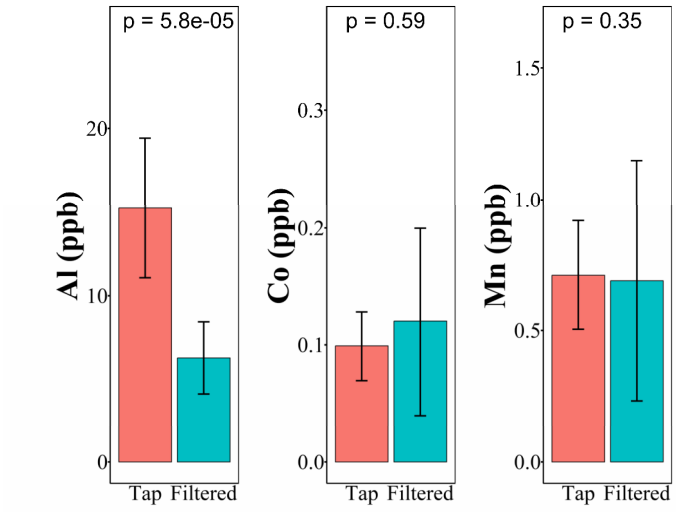


Impact of Filters - HM

- A significant reduction in Iron
- Significant reduction in Pb

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Heavy Metals - CCL

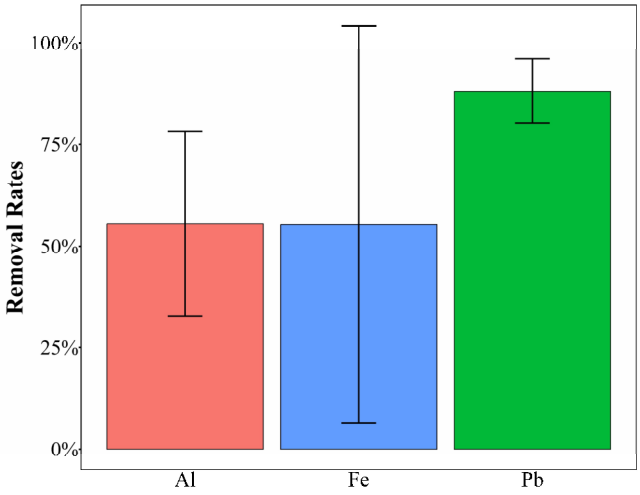


Impact of Filters - HM

- A significant reduction in Iron
- Significant reduction in Pb
- Significant reduction Al
- Could indicate that these are all precipitated metals
  - Removed physically

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Heavy Metals Removal Rates



Impact of Filters - HM

- A significant reduction in Iron
- Significant reduction in Pb
- Significant reduction Al
- Could indicate that these are all precipitated metals
  - Removed physically
- High removal of these metals
  - ~90% removal of Lead!

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CONCLUSIONS

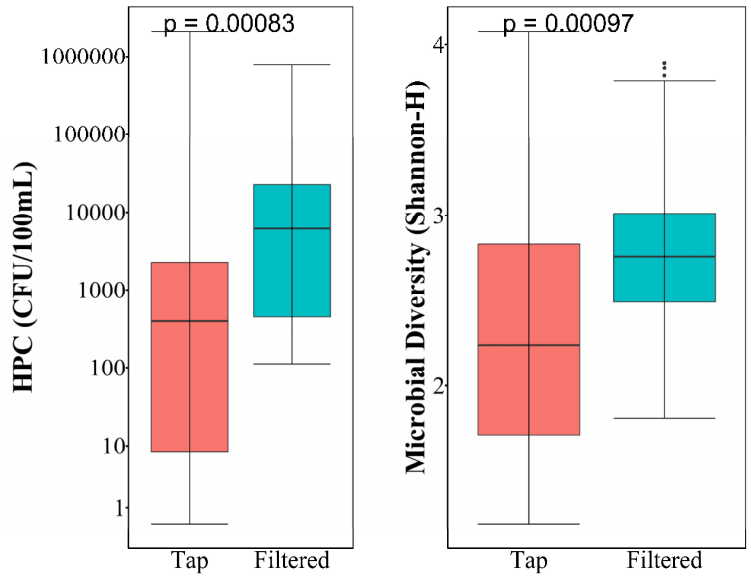
The major impact on water quality is removal of chlorine and precipitated metals, such as lead

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HOW DO POU FILTERS IMPACT MICROBIAL EXPOSURES?

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Microbial Regrowth

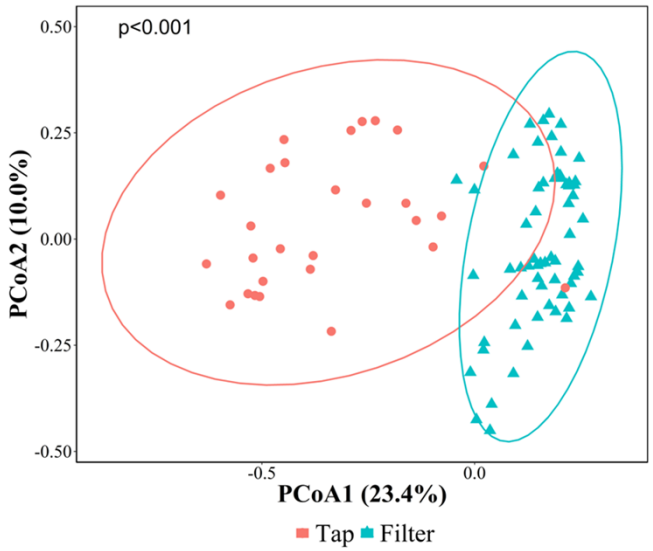


Impact of Filters – Microbes

- Significant regrowth in microbes
  - Order of magnitude growth
  - >log-2 growth
- More microbes grow
  - Increase in diversity

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Microbial Regrowth

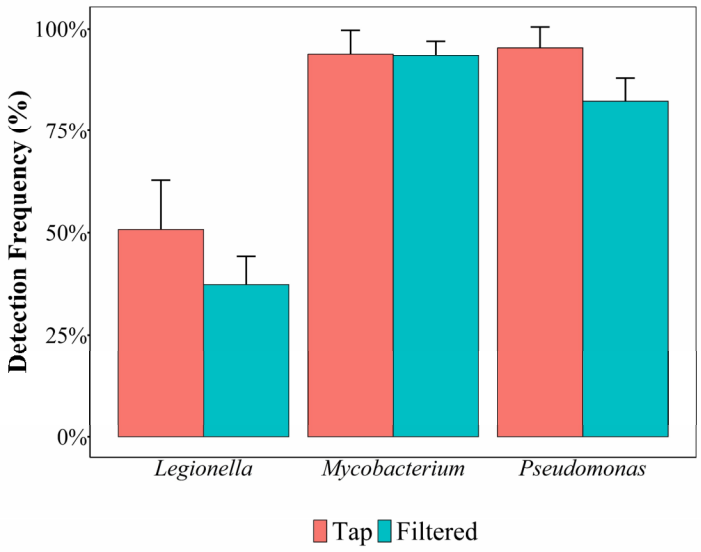


Impact of Filters – Microbes

- Significant regrowth in microbes
  - Order of magnitude growth
  - >log-2 growth
- More microbes grow
  - Increase in diversity
- Related to Shift in Microbial Community
  - Seen by PCoA Figure

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Pathogen Detection

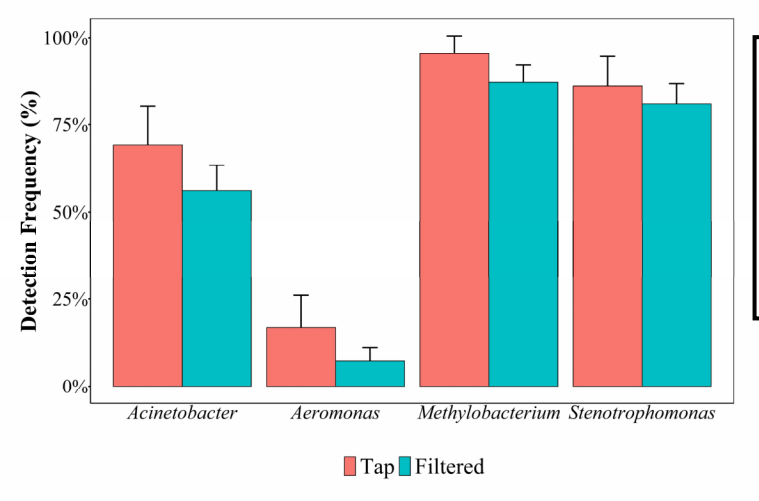


Impact of Filters – Pathogens

- CCL Pathogens:
  - Detection rates were similar
  - *Legionella* <50%
  - *Mycobacterium* >90%

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Pathogen Detection

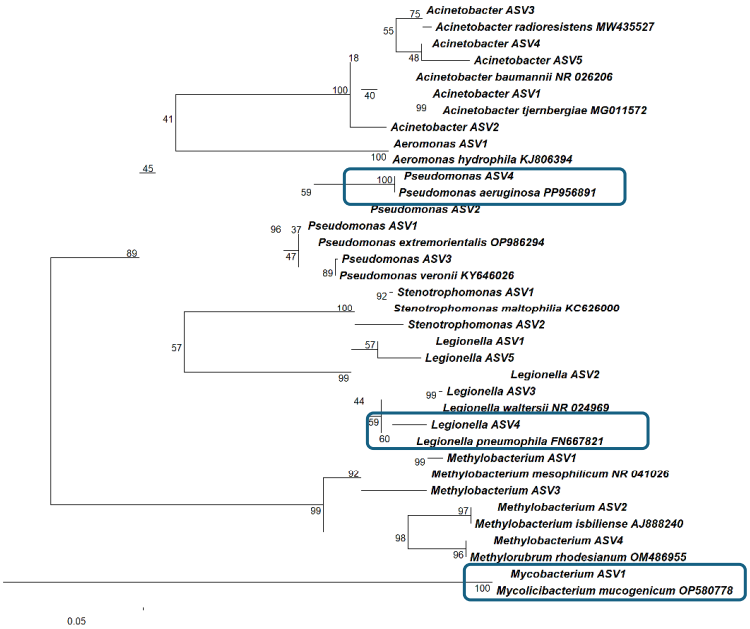


Impact of Filters – Pathogens

- CCL Pathogens:
  - Detection rates were similar
  - *Legionella* <50%
  - *Mycobacterium* >90%
- *Methylobacterium* and *Stenotrophomonas* >80%

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Pathogen Detection

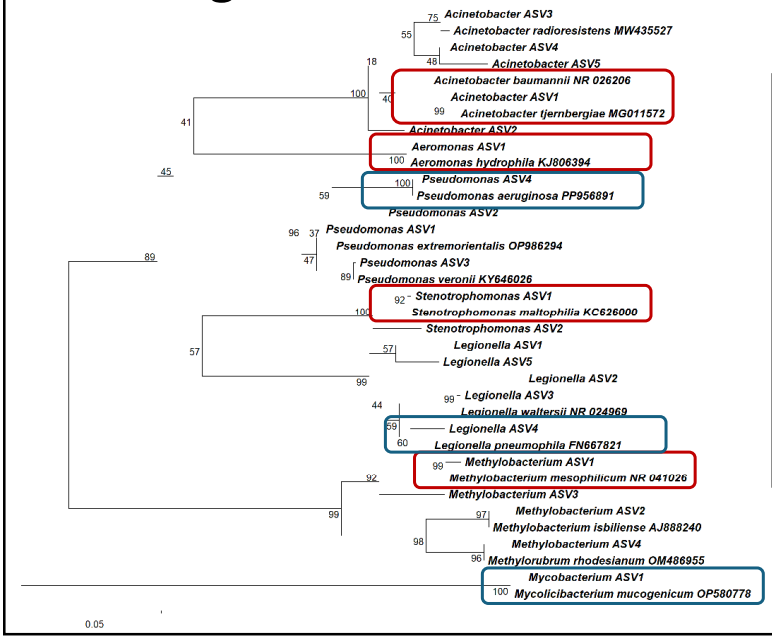


Impact of Filters – Pathogens

- Not all strains are pathogenic
  - CCL:
    - *Legionella*: 1 ASV
    - *Mycobacterium:* 1 ASV
    - *Pseudomonas*: 1ASV

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Pathogen Detection



Impact of Filters – Pathogens

- Not all strains are pathogenic
  - CCL:
    - *Legionella*: 1 ASV
    - *Mycobacterium:* 1 ASV
    - *Pseudomonas*: 1ASV
  - *Potential OPs:*
    - *Acinetobacter: 1ASV*
    - *Aeromonas: 1ASV*
    - *Methylobacterium: 1ASV*
    - *Stenotrophomonas: 1ASV*

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CONCLUSIONS

The major impact on water quality is removal of chlorine and precipitated metals, such as lead

At the same time, microbial regrowth occurred including with potential pathogens

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RISK CHANGES FROM POU FILTER

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Risk Assessment Models

- $Risk = 1 - EXP\{-k * dose\}$
  - If $Risk < 0.001 \rightarrow Risk = k * dose$
  - $k = slope\ factor$
  - $dose = exposure\ dose$
    - $dose_{HM} = C_{HM} * 2.3\ L/day$
    - $dose_{path} = RA_{path} * HPC * 2.3\ L/day$
- Many contaminants do not have sufficient data for slope factors
  - $Relative\ Risk = \frac{Risk_{filter}}{Risk_{tap}} = \frac{k*dose_{filter}}{k*dose_{tap}} = \boldsymbol{\frac{dose_{filter}}{dose_{tap}}}$

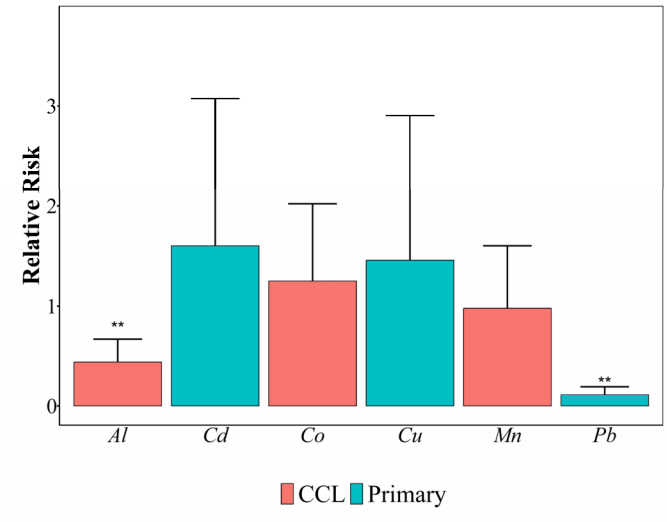
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Heavy Metal Risk

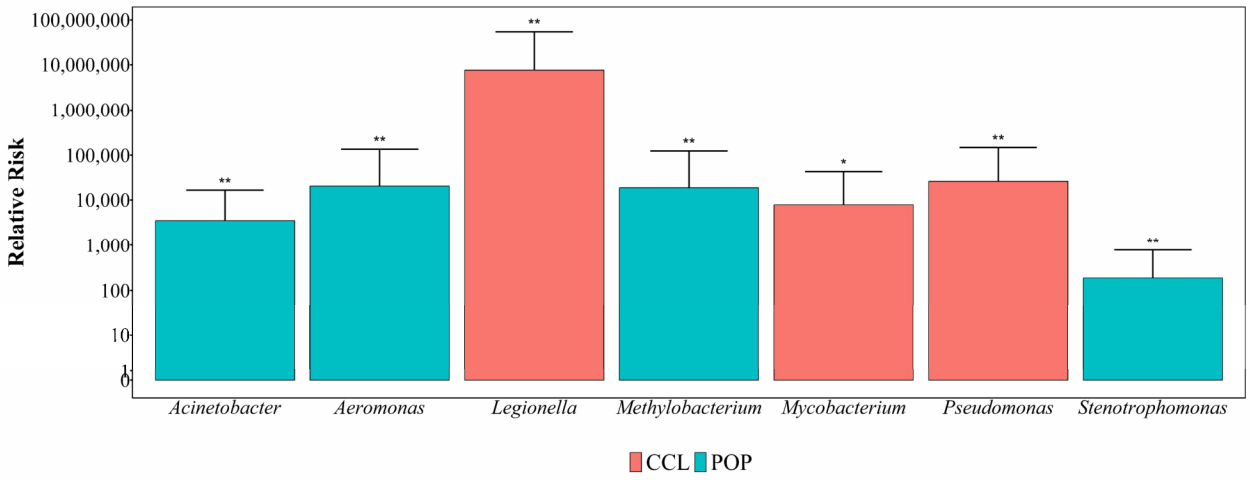


Impact of Filters – HM Risk

- Only metals with significant change
  - Pb: 89% reduction in risk
  - Al: 64% reduction in risk

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Pathogen Risk



- All pathogenic ASVs significantly increased in risk
- *Legionella* had a 7,000,000 increase in risk from Filter Use

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CONCLUSIONS

The major impact on water quality is removal of chlorine and precipitated metals, such as lead

At the same time, microbial regrowth occurred including with potential pathogens

While carbon filters could reduce Lead exposure risks by 90%, exposure risks for potential pathogens increased by up to 1,000,000 times.

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