Fouling in hollow fiber membrane microfilters used for household water treatment

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Pure Water FOR THE WORLD

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Sawyer PointOne Filter

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Sawyer PointOne Filter

Filter

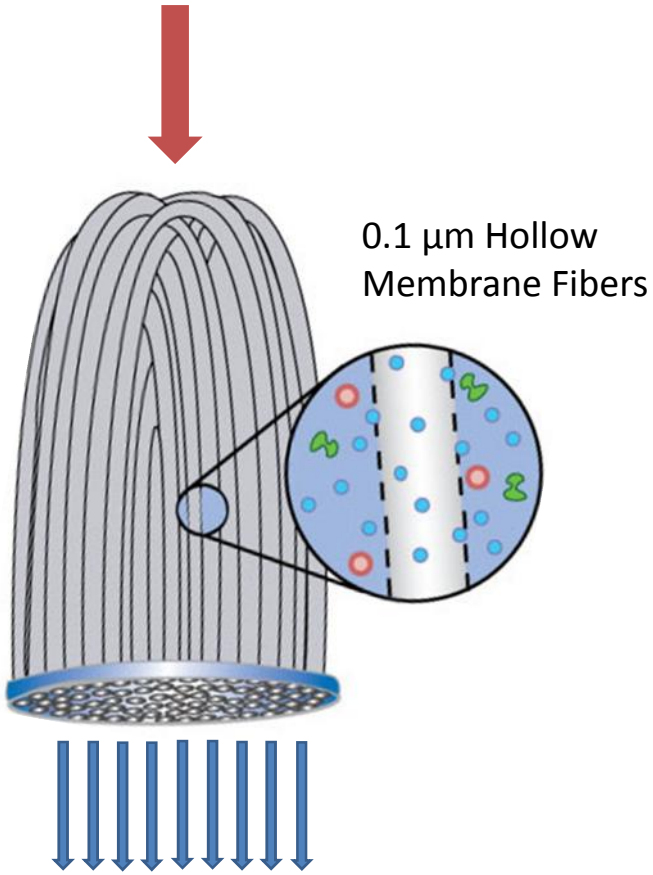

Image modified from: http://sawyer.com/international/saving-lives/our-technology/

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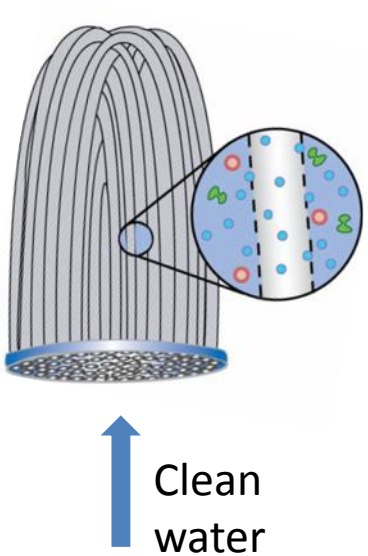
Sawyer PointOne Filter: Maintenance

- Pretreat turbid source water (settling, pre-filtering)
- Backwash with clean water when flow slows



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Sawyer PointOne Filter

- Laboratory Efficacy:
  - > 5-log removal of protozoa (>99.999%)
  - > 6-log removal of bacteria (>99.9999%)

  With epidemiological evidence, would meet WHO *Limited Protection* target

- Life Span:

"10+ years"

"Most Sawyer Water Filters come with a 1 million gallon guarantee"

"With proper maintenance the filter never needs replacing "

"Life Expectancy: More than 3 Million Liters"

"Decades"

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Hydreion 2005 *Microbiological Testing of the Sawyer 7/6B Filter*. www.sawyer.com/documents/field-micro.pdf
http://sawyer.com/international/products/sawyer-pointone-pail-water-filter/
http://sawyer.com/products/type/water-filtration sawyer.com/wp-content/uploads/2013/12/brochure.pdf

PWW Pilot Project

- Pure Water for the World (PWW) installed 200 PointOne filters in Honduran communities
  - Users were given training on use and maintenance
  - Follow-up household visits and microbiological testing

6 Filters
- No external damage
- Users demonstrated correct backwashing

Removal Efficiencies

E. Coli: >99.6%

Turbidity: 98-99%

Removal Efficiencies

E. Coli: 54%

Turbidity: 59%

These filters removed from the field and investigated in the laboratory

Methods

1) Microbiological and Turbidity Testing

- 6 used filters
- 1 new filter

– Sterile water passed through filters

↳ Effluent turbidity measured, and swabbed onto trypticase soy agar (TSA) plate to identify bacterial presence

– Filters cleaned (soaked in hot water 30 min, backwashed 4 times, soaked in vinegar 30 min, backwashed 4 times)

– Additional sterile water passed through filters

↳ Effluent tested to differentiate bacteria:

- Bacteria Presence: Trypticase Soy Agar (TSA) Plate
- Total Coliform: Eosin methylene blue (EMB) plate
- Fecal Coliform: MacConkey agar (MAC) plate
- *E. Coli*: MUG-agar plate

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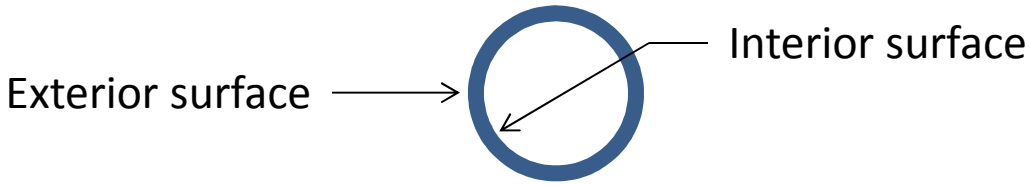
Methods

2) Scanning Electron Microscopy (SEM)

- 1 used filter
- 1 new filter

- Cut open and imaged one membrane fiber from each filter
- Energy Dispersive Spectroscopy (EDS) used to identify elemental surface composition (top 1-10 µm)
  - Exterior and interior fiber surfaces: New and Used Filters



Hollow fiber membrane
Cross-section

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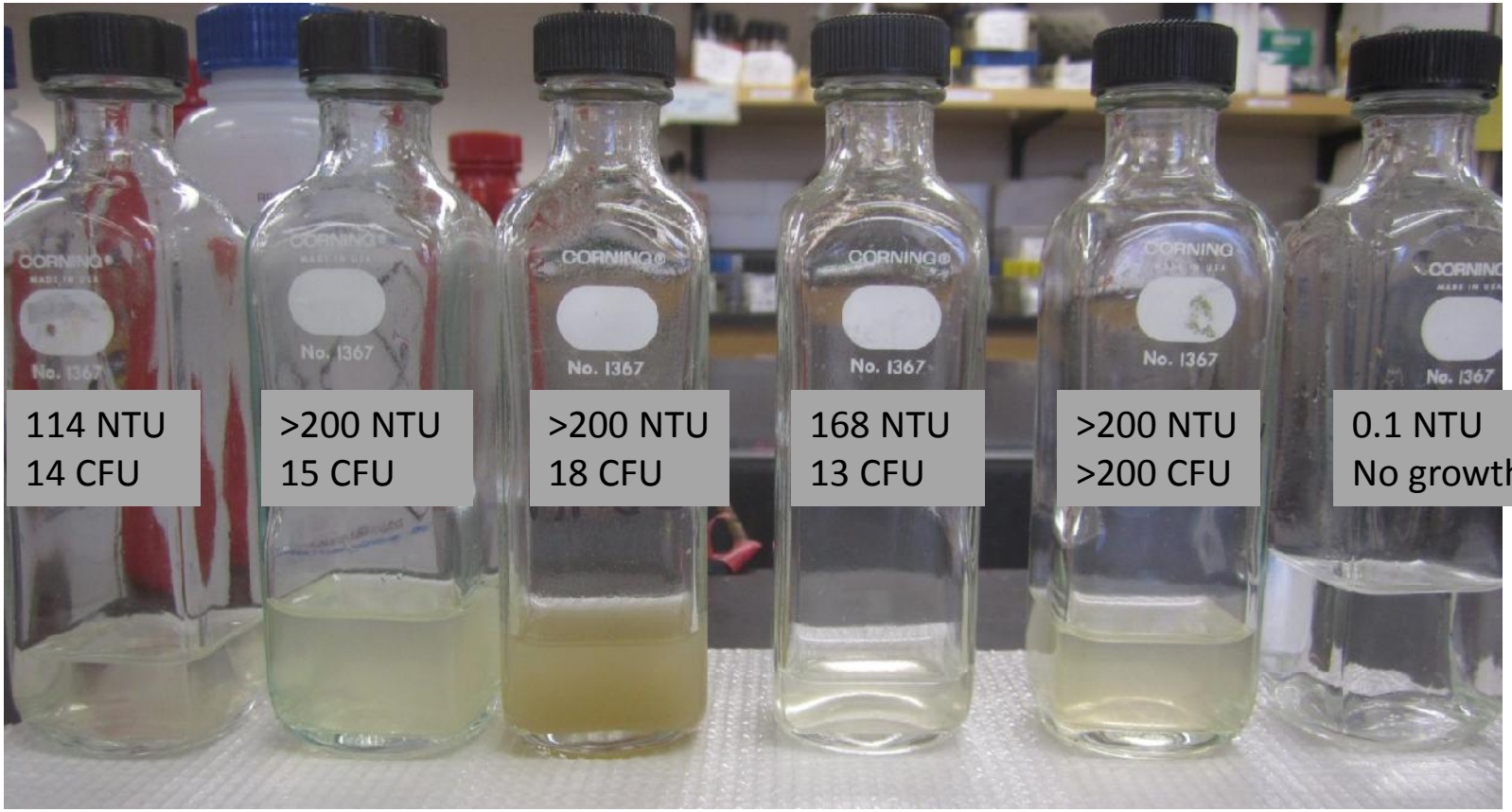
Results: Turbidity & Microbiological Testing



Turbidity:	114 NTU	>200 NTU	>200 NTU	168 NTU	>200 NTU	0.1 NTU
Bacteria:	14 CFU	15 CFU	18 CFU	13 CFU	>200 CFU	No growth

NTU: Nephelometric Turbidity Units

CFU: Colony Forming Unit

Field-removed filters - Before Cleaning
(one blocked - no effluent)

New filter

Results: Turbidity & Microbiological Testing

- After Cleaning (soaking and backwashing):
  - All sterile water effluent still visually turbid (> 10 NTU), except new filter
  - Effluent from used filters (2 tested):
    - **Positive for Total Coliform** (lactose-fermenting) Presence (EMB plate and MAC plate)
    - **Negative for *E. Coli*** Presence (MUG-agar plate)
  - New filter effluent: negative for all bacteria

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Results: Scanning Electron Microscopy

Filter casings cut open (after cleaning) and photographed at the inlet end

New Filter

Used Filter

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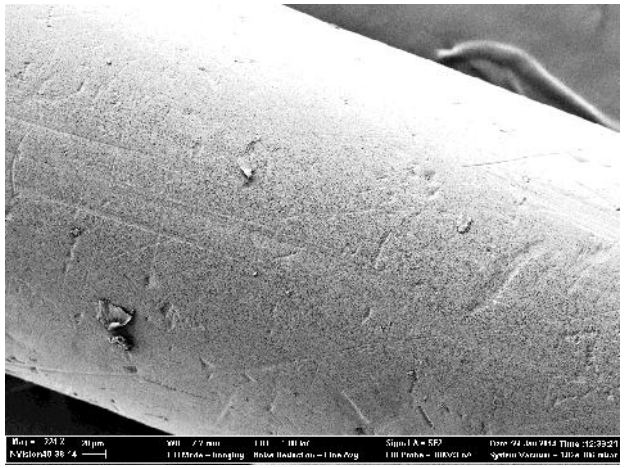
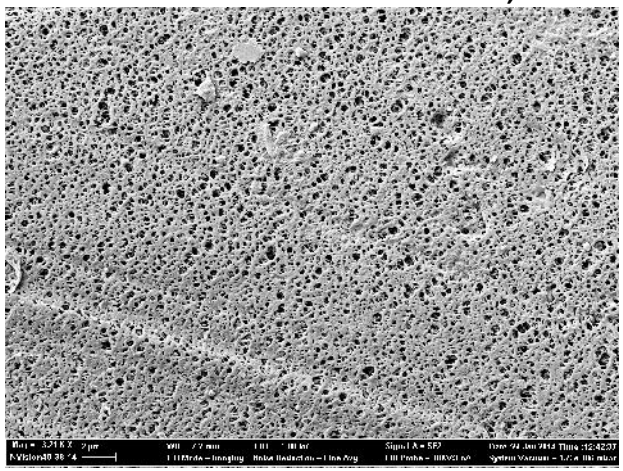
Results: Scanning Electron Microscopy

New Filter Membrane:

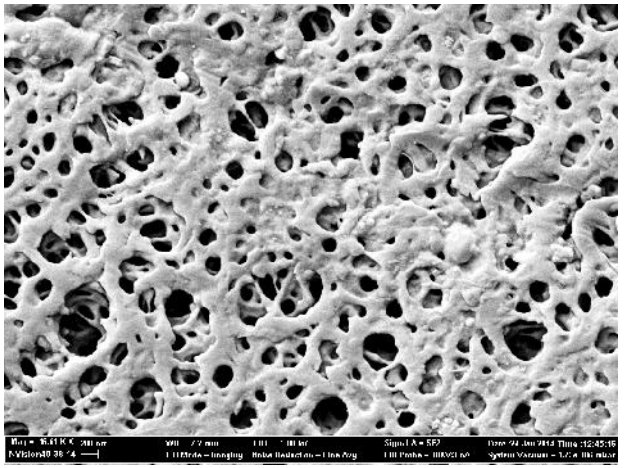
224x



3,210x

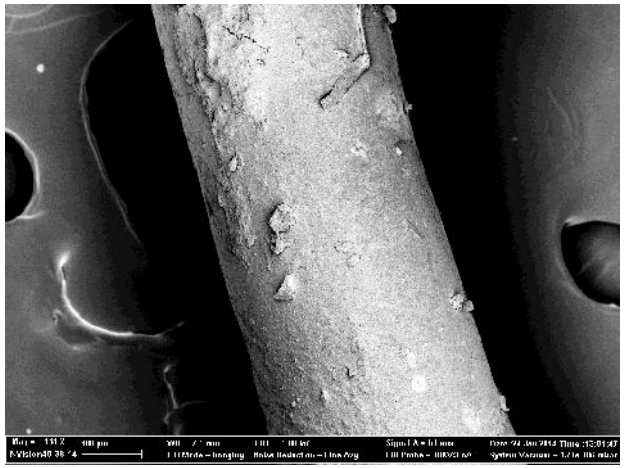


16,610x

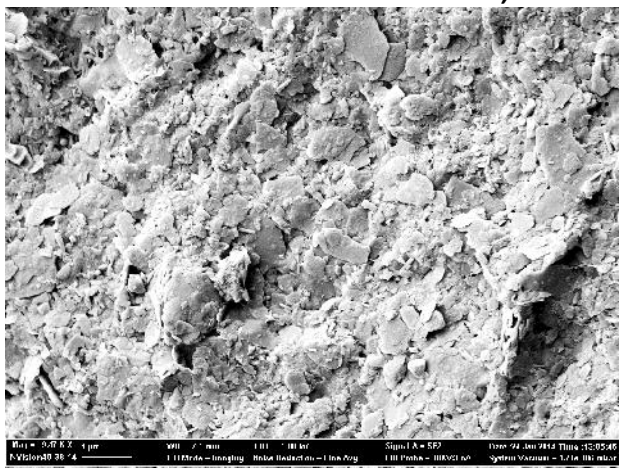


Used Filter membrane (after cleaning):

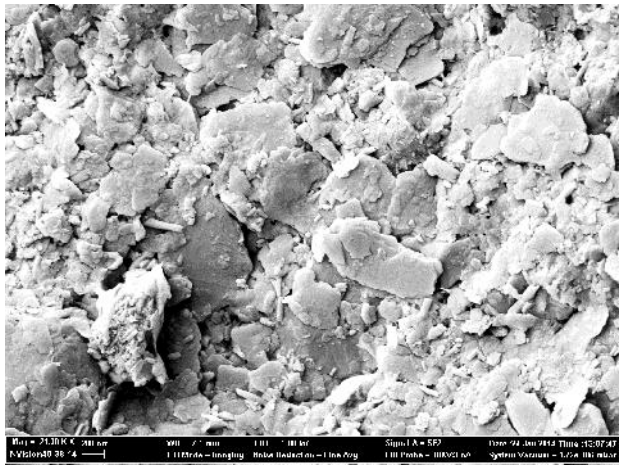
114x



9,470x



21,300x



Results: Scanning Electron Microscopy

- Elemental Surface Composition

Element	Normalized weight %			
	New membrane, outer surface	New membrane, inner surface	Used membrane, outer surface	Used membrane, inner surface
Carbon	75.4	70.0	19.6	58.5
Oxygen	13.3	19.8	34.9	15.1
Sulfur	6.4	8.8	2.2	14.4
Nitrogen	0.0	1.5	0.0	0.0
Silicon	0	0	8.2	1.4
Aluminum	0	0	6.6	1.2
Iron	0	0	4.4	0.7
Lead	0	0	1.8	8.0
Potassium	0	0	0.8	0.2
Calcium	0	0	0.5	0.4
Magnesium	0	0	0.4	0.1

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Membrane Fouling

- *Fouling* – or membrane blockage – is caused by organic, inorganic, and bacterial constituents
- Depends on:
  - Membrane Characteristics
  - Operating conditions
  - Physical / chemical properties of foulants
  - Solution chemistry

    turbidity, organic content, hardness, heavy metal ions, particulates, biofilm forming bacteria
- Fouling is a challenge in all membrane applications (drinking water, wastewater, biomedical, etc.)

Well-recognized, but complex obstacle

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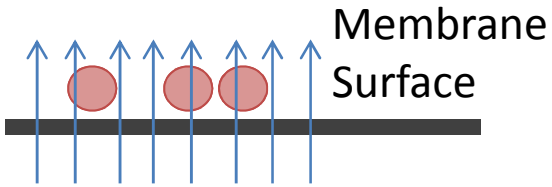
Membrane Fouling

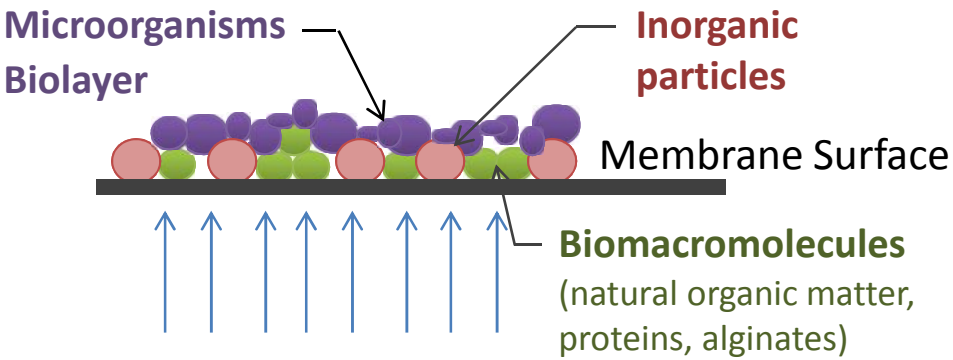
Reversible Fouling

- Foulants create “cake” layer
- Can be removed by physical processes like backwashing



Irreversible Fouling

- Solutes adsorb to pores



- Physical processes insufficient to remove
- Need chemical cleanings
  - Acidic, Alkaline, Biocide

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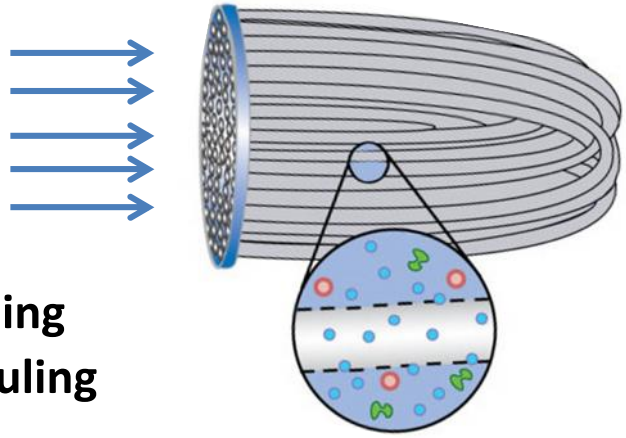
PointOne Filter Membrane Fouling

Burst Fibers?

"Be forceful" when Backwashing



✓ **Reversible Fouling**

X **Irreversible Fouling**

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Summary

- Six Sawyer PointOne filters were found to have *low bacterial and turbidity removal rates* after 23 months of household use
- When sterile water was introduced, it exited these filters with *higher turbidity and bacteria loading*
- At least one membrane was *irreversibly fouled* on interior and exterior membrane surfaces
  - inorganic particles, organic biomacromolecules, and biofouling
- One filter appeared to have *burst fibers*, potentially allowing short-circuiting of water

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Limitations

- Few filters were analyzed
  - 6 out of 200 installed by PWW
- Limited testing of source water quality parameters
  - *Mean turbidity 62 NTU (range 7-87 NTU)*
- Self-reported user behavior cannot be verified

How widespread of an issue is this?

What water quality parameters contributed to fouling?

Can we rule out user error?

Are these results applicable to other situations?

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Discussion

Identifies opportunities for **future research:**

- Characterize filter effectiveness
- Understand source water quality effect on performance
- Investigate the extent of membrane fouling and bacterial growth
- Establish a cleaning regimen to manage fouling
- Develop an appropriate filter lifespan, end-of life indicator

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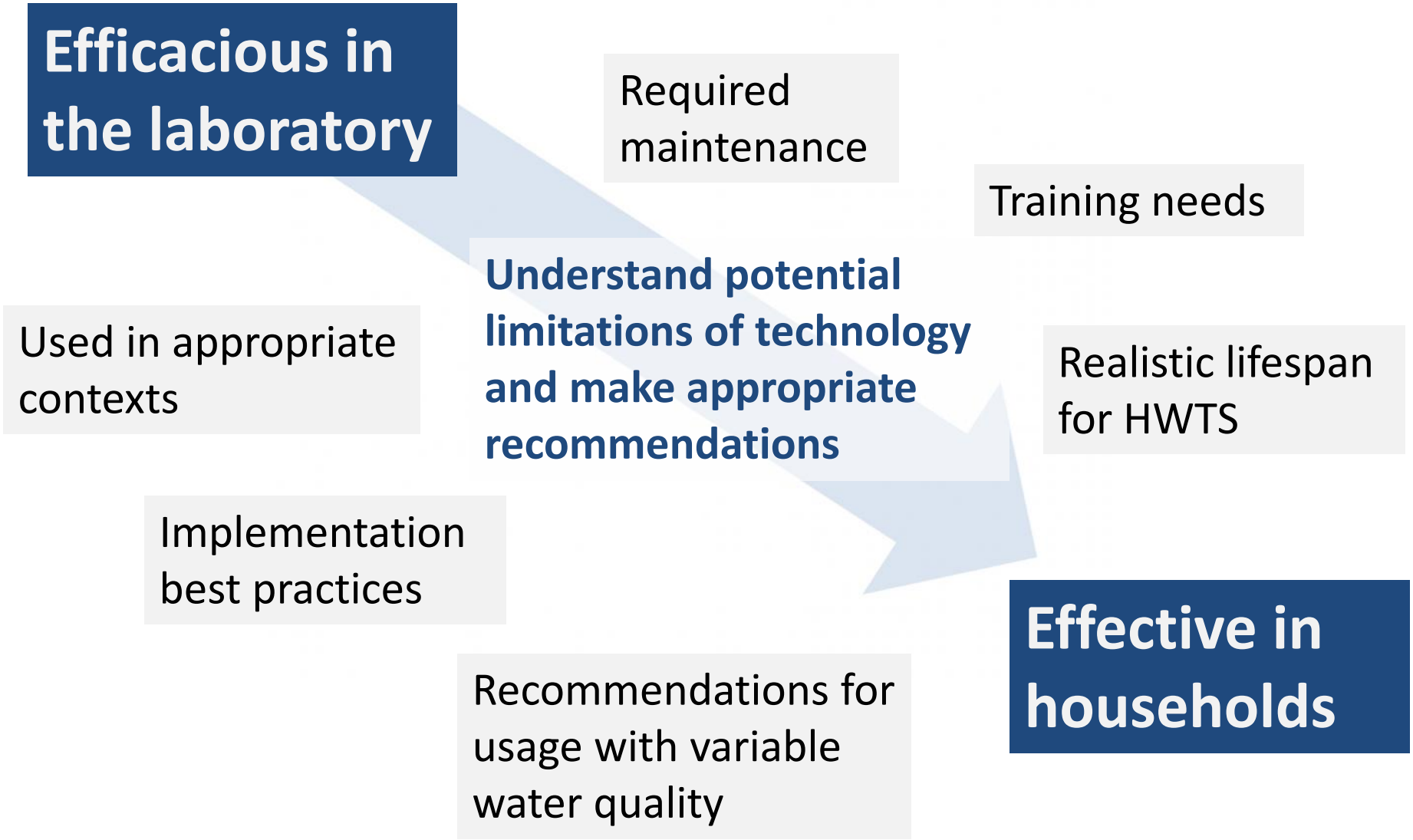
Discussion


Efficacious in the laboratory
Required maintenance
Training needs
Understand potential limitations of technology and make appropriate recommendations
Used in appropriate contexts
Realistic lifespan for HWTS
Implementation best practices
Effective in households
Recommendations for usage with variable water quality

Thank You

Co-authors, PWW Honduras staff

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Photos courtesy of Justine Rayner and Anna Murray