

Iron Oxide Amended BioSand Filters for Virus Removal

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Overview

- Introduction and objectives
- BSF: removal efficacy and potential problems
- Amending the BSF to increase virus removal
- Experiments
- Conclusions

The Guatemala Water Project

In Guatemala

- Design and implementation of a water treatment system for Socorro, Guatemala
- Health education programs

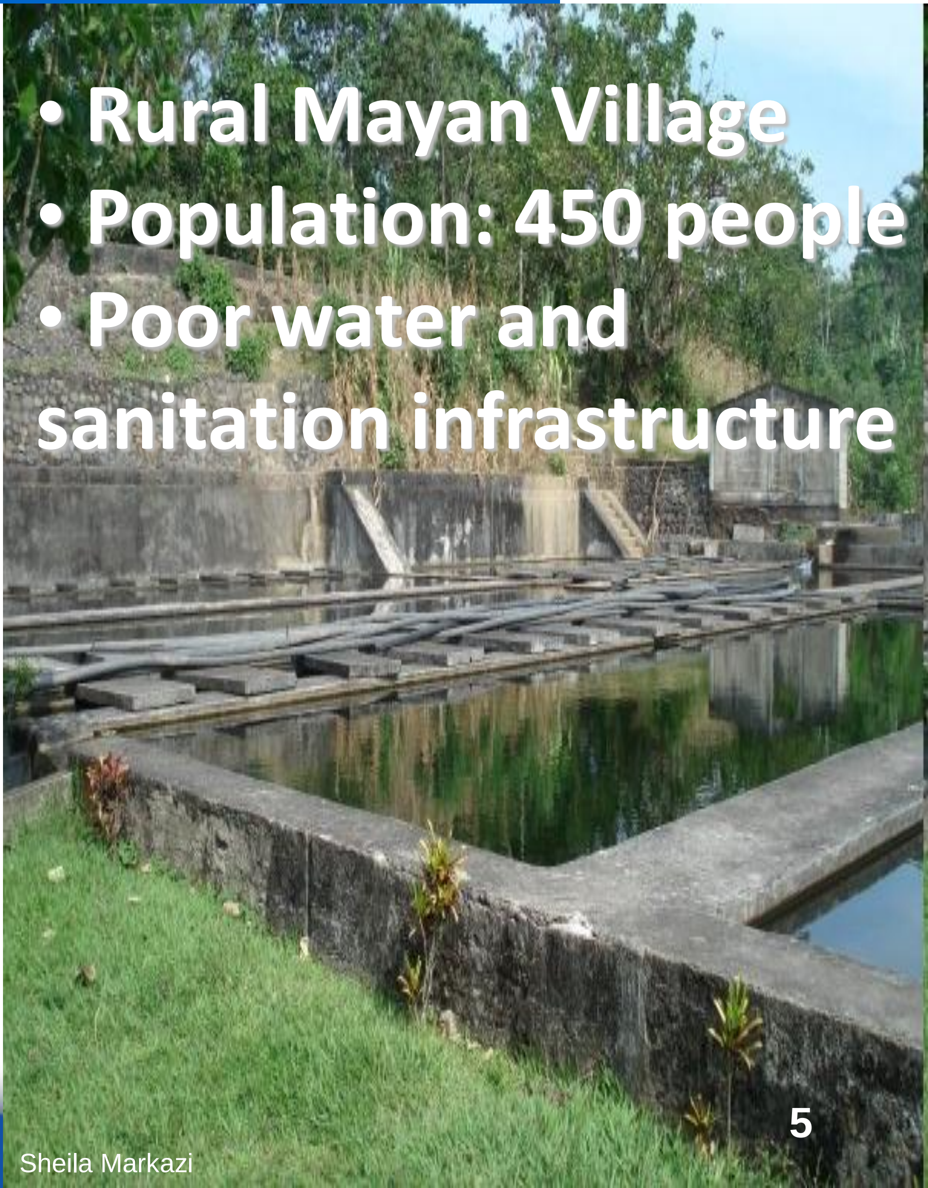
The Guatemala Water Project

At home

- Community outreach
- Promote awareness of ongoing water crisis
- Hands on activities for students to learn about water filtration and the importance of clean water

The Guatemala Water Project

- **Rural Mayan Village**
- **Population: 450 people**
- **Poor water and sanitation infrastructure**



Sheila Markazi

The Need For Clean Water

WUQU' KAWOQ

STRENGTHENING MAYAN LANGUAGE AND MEDICINE

- Identified by Wuqu' Kawoq
- High prevalence of waterborne illnesses and malnutrition
- Efforts made medically, but sustainable solution is required

Implementation

- 120 BSFs installed since Dec. 2009
- Community education
- Chlorination problems
- Rotavirus causes 600,000 deaths worldwide[1]

[1]Parashar et al., 2006

Design Objective

- To create a point-of-use system that eliminates bacteria, helminthes, protozoa, *and* viruses
- To improve upon past designs with an innovative approach using zerovalent iron
- To ensure WHO drinking water standards are met

Design Team

- Awarded EPA P3 Phase 1 ($10,000)
- Globally Oriented Academic Learning (GOAL) Program
  - Professor Helen Nguyen
  - 3 graduate students
  - 15 undergraduate researchers

Design Team

- **Principal Investigator**
  Prof. Helen Nguyen
  - **Research Leads**
    Ian Bradley and Anthony Straub
    - **MS2 Team**
      - Student Researcher
      - Student Researcher
    - **E. Coli Team**
      - Student Researcher
      - Student Researcher
    - **Additional Groups**
      - Student Researcher
      - Student Researcher

- **Research Mentors**
  - Heather Goetsch
  - Ofelia Romero
  - Leo Gutierrez

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BSF Performance

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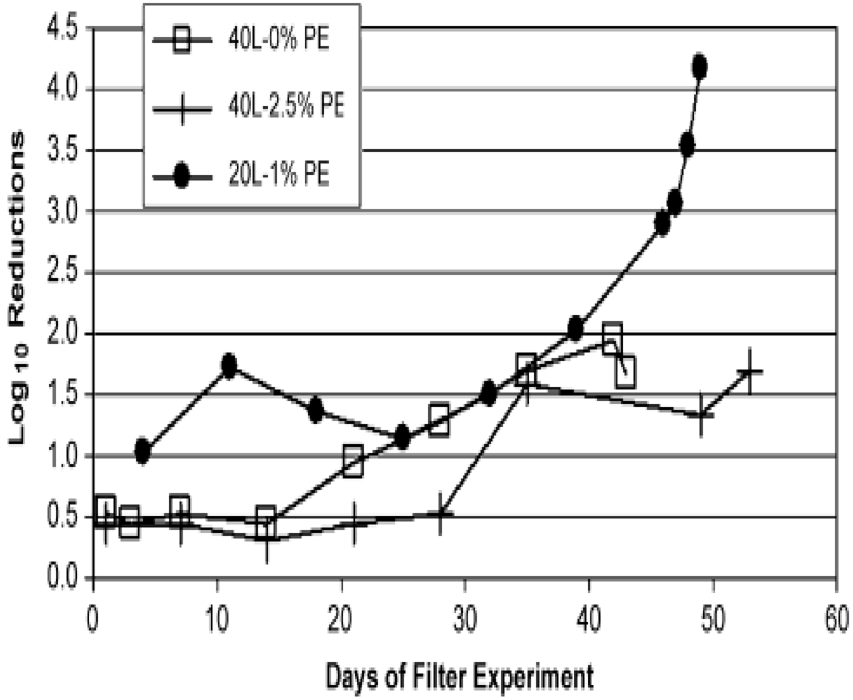
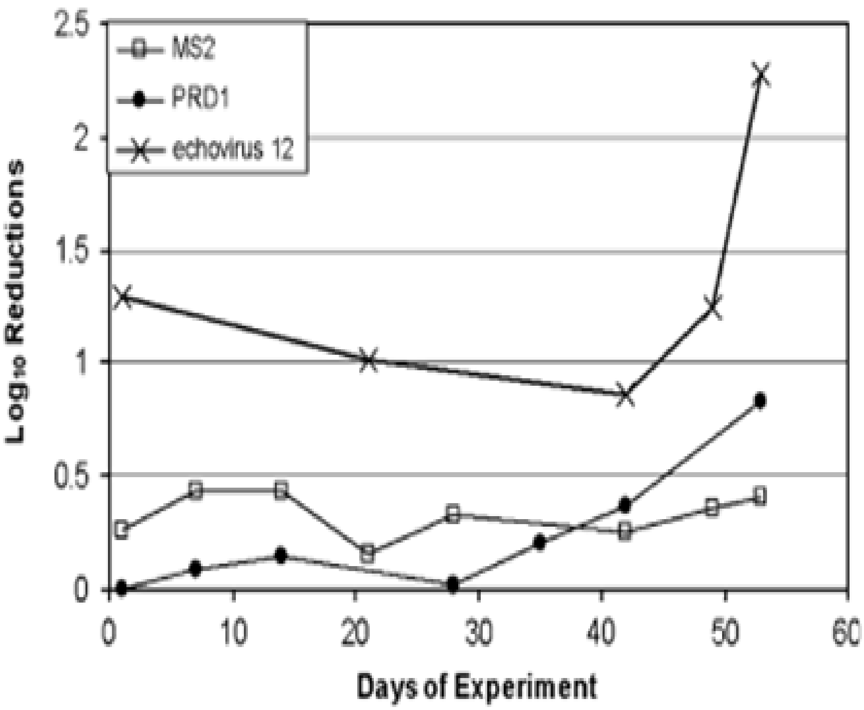
E. coli



3 different viruses



Elliott, M.A., et al. *Water Research, 2008.* ***42(10-11): p. 2662-2670.***

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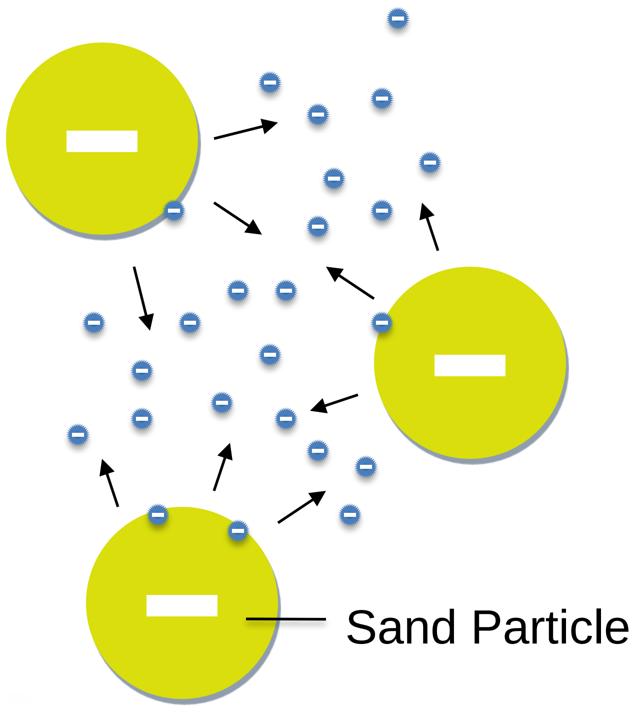
Problem: Low Virus Removal

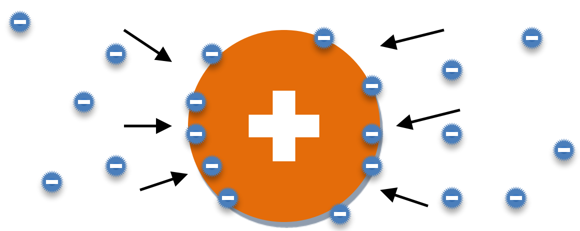


- Retention by the BSF depends on deposition
- Both virus surfaces and sand media negatively charged in environmental water
  - MS2 IEP 3.6[a]
  - Rotavirus IEP 4.5[a]
  - Quartz Sand IEP 2.44[b]

[A]Gutierrez, L., et al., *Adsorption of rotavirus and bacteriophage MS2 using glass fiber coated with hematite nanoparticles*. Water Research, 2009. **43**: p. 5198-5208.
[B]A. Jada et. al. "Surface charge and adsorption from water onto quartz sand of humic acid" 2005

Solution: Increasing Virus Attachment

- Addition of zerovalent iron to sand media has been shown to remove viruses in column studies



- Electrostatic interactions responsible for adsorption
  - Positively charged oxide (Fe^{3+}, non-soluble)
  - Iron hematite (Fe_2O_3) IEP ≈8.0

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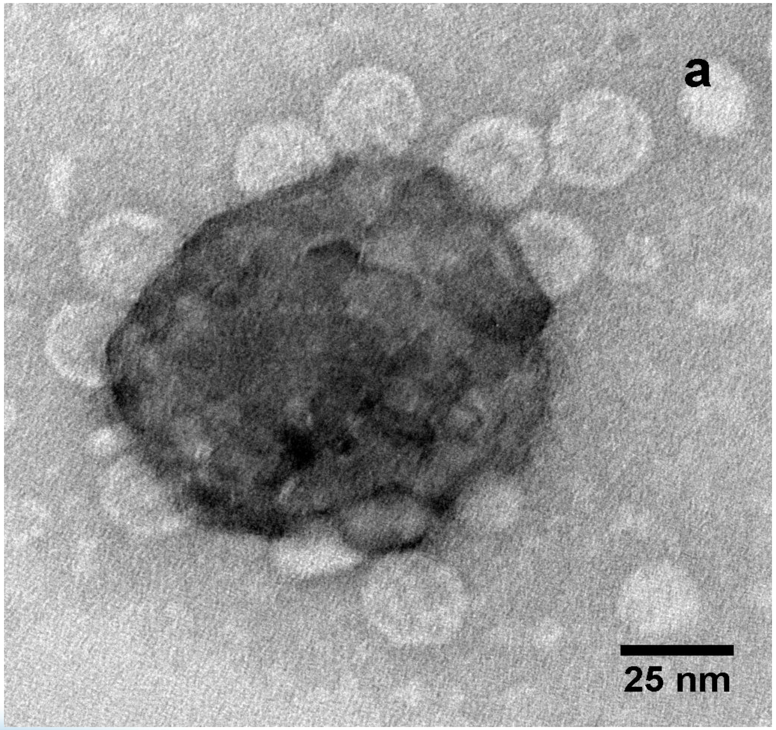
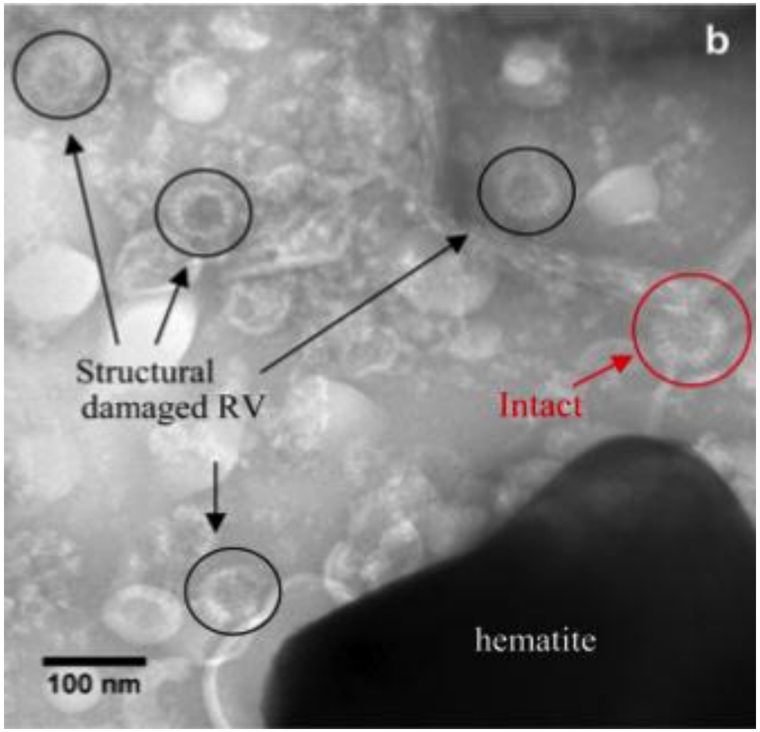
Virus Adsorption to Iron Oxides

MS2

Rotavirus





Gutierrez, L., et al., *Adsorption of rotavirus and bacteriophage MS2 using glass fiber coated with hematite nanoparticles*. Water Research, 2009. **43**: p. 5198-5208.

Design Solution

- Iron-amended BSF
  - Organic compounds (BOD) consumed in the biologically active layer
  - Bacteria and other larger pathogens strained by the biofilm and sand media
  - Viruses adsorbed to iron oxides via electrostatic interactions

Experiments: Overview

- Continuous flow through saturated sand columns
- 1 PV, daily charged columns simulating BSFs
- Household-scale, plastic BSFs
- Household-scale, concrete BSFs

Continuous Flow Columns

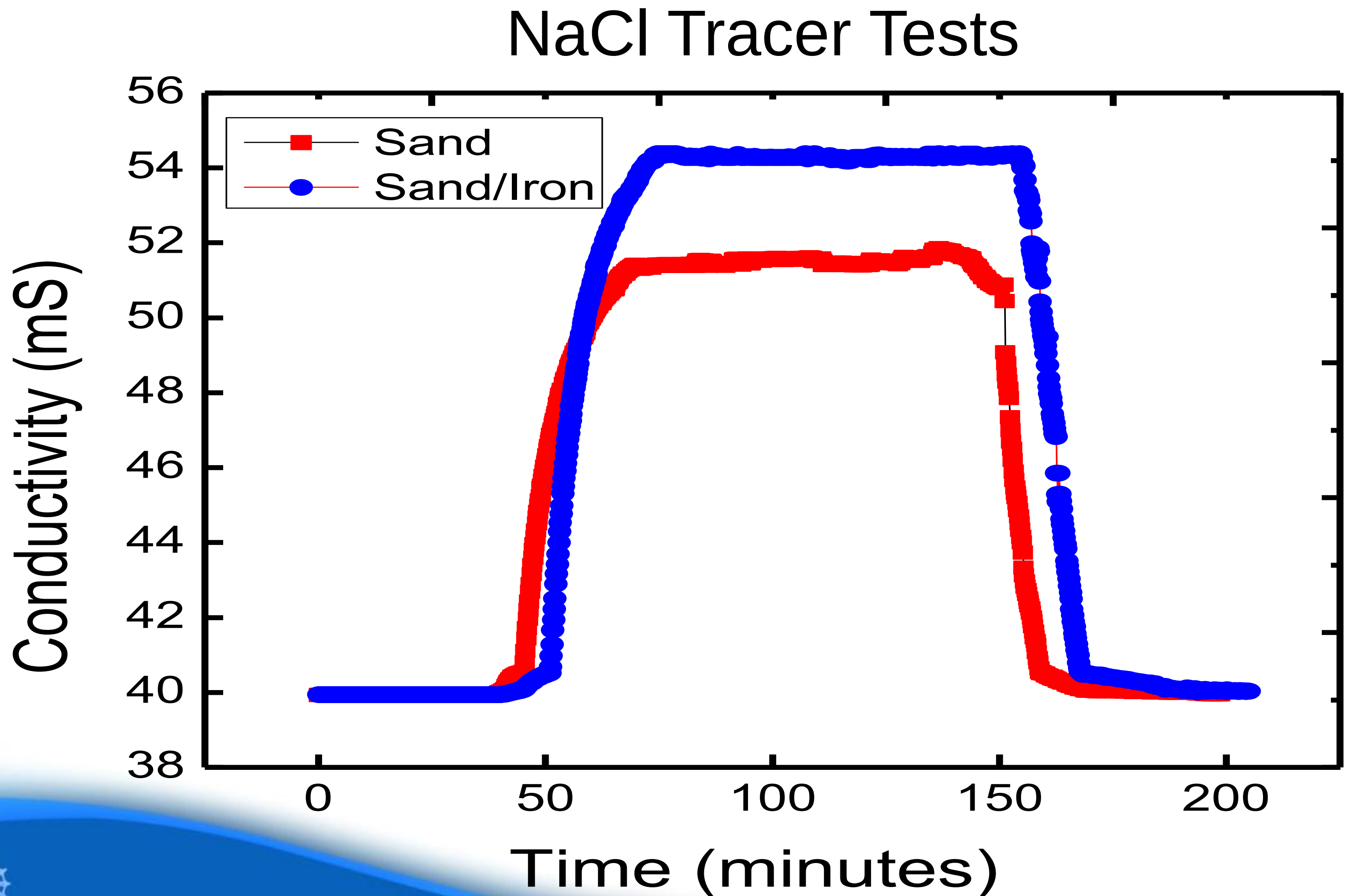
Two columns:

- Sand Only
- Sand/Iron mixture (90% Sand, 10% Iron)

Continuous Flow Columns

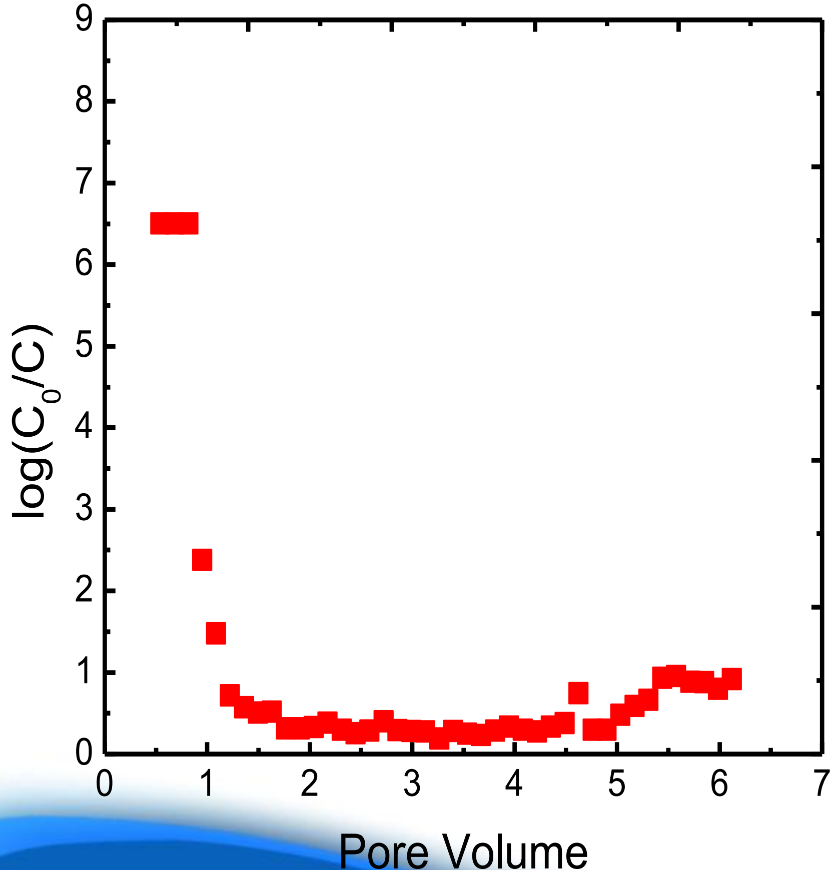
- Initial Testing
  - Newmark Aquifer water
  - MS2 bacteriophage
  - PH ~7
  - No biofilm

Continuous Flow Columns

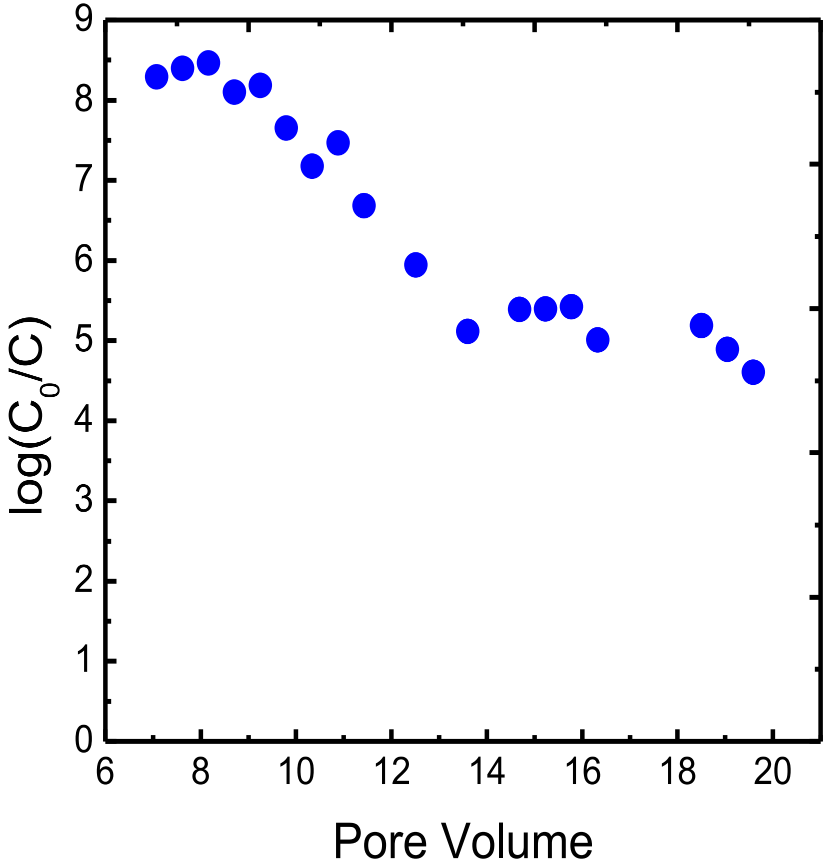


Continuous Flow Columns

Sand



Iron



Daily Charged Columns

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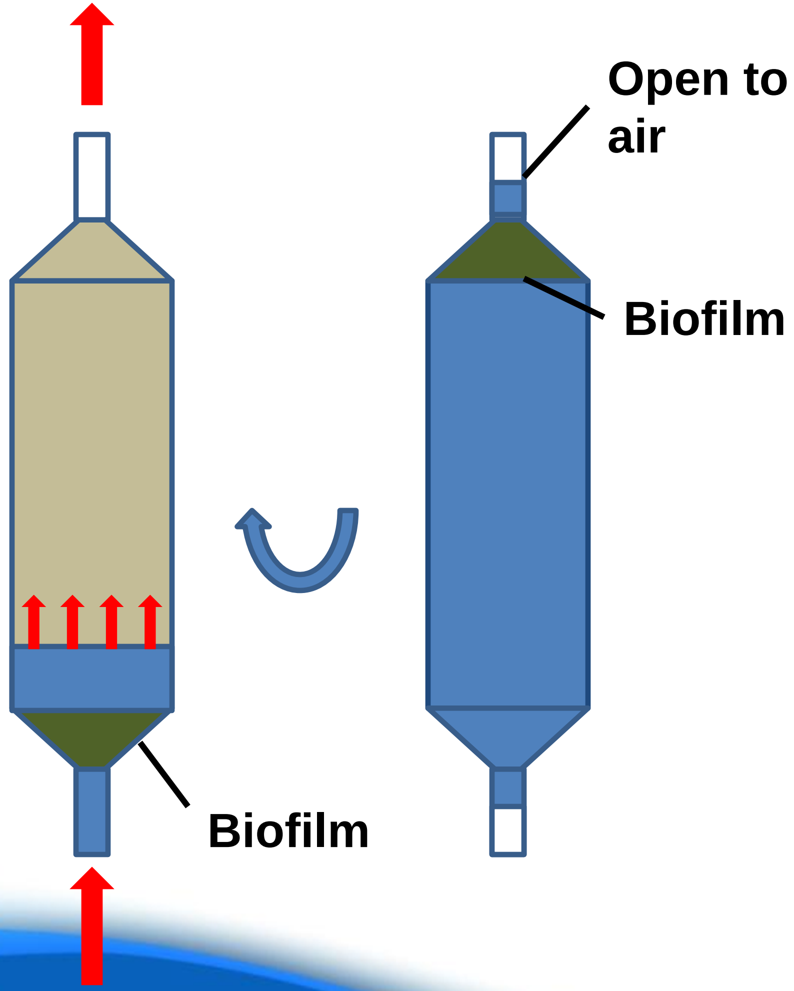
Mixed

Band

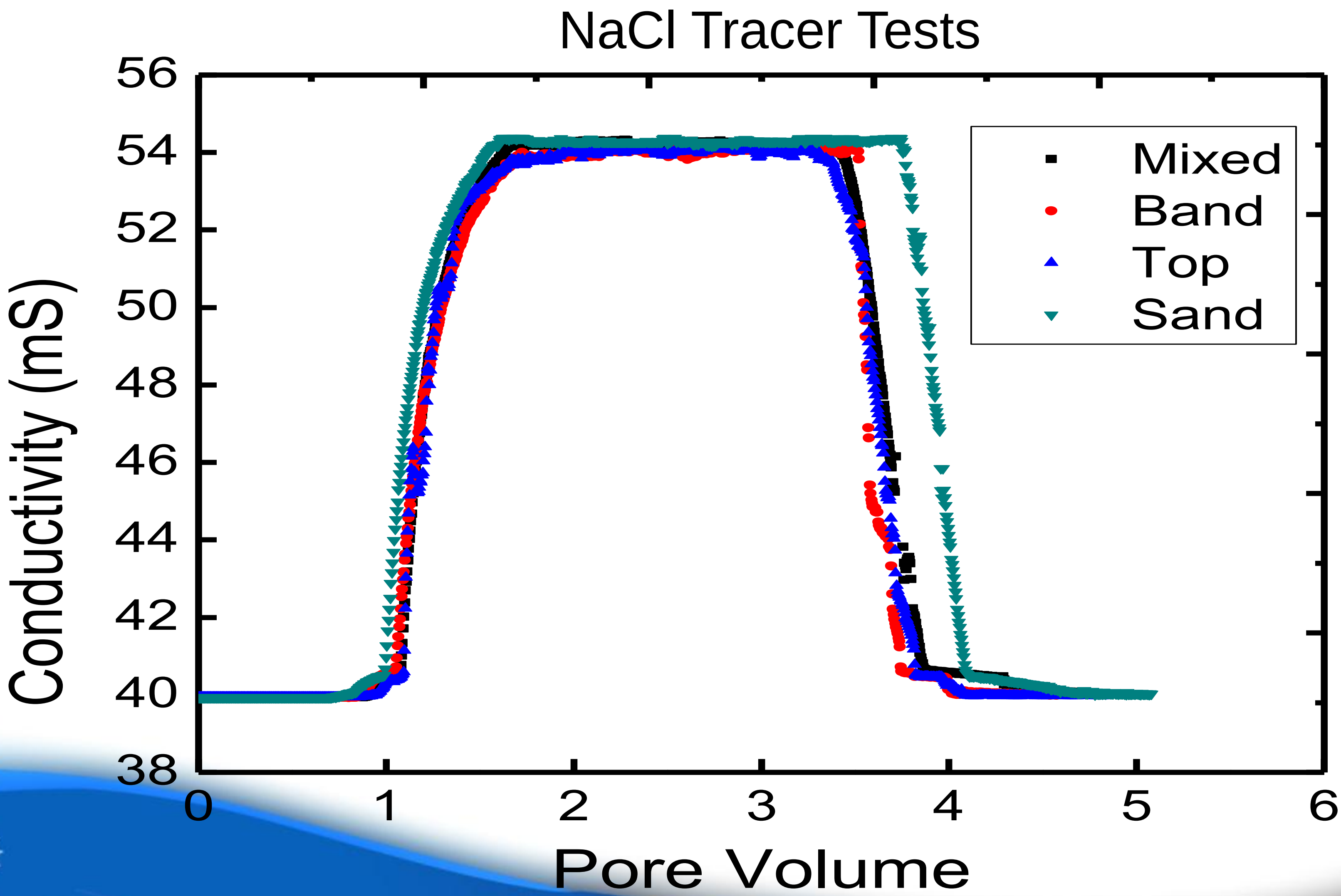
Top

Daily Charged Columns

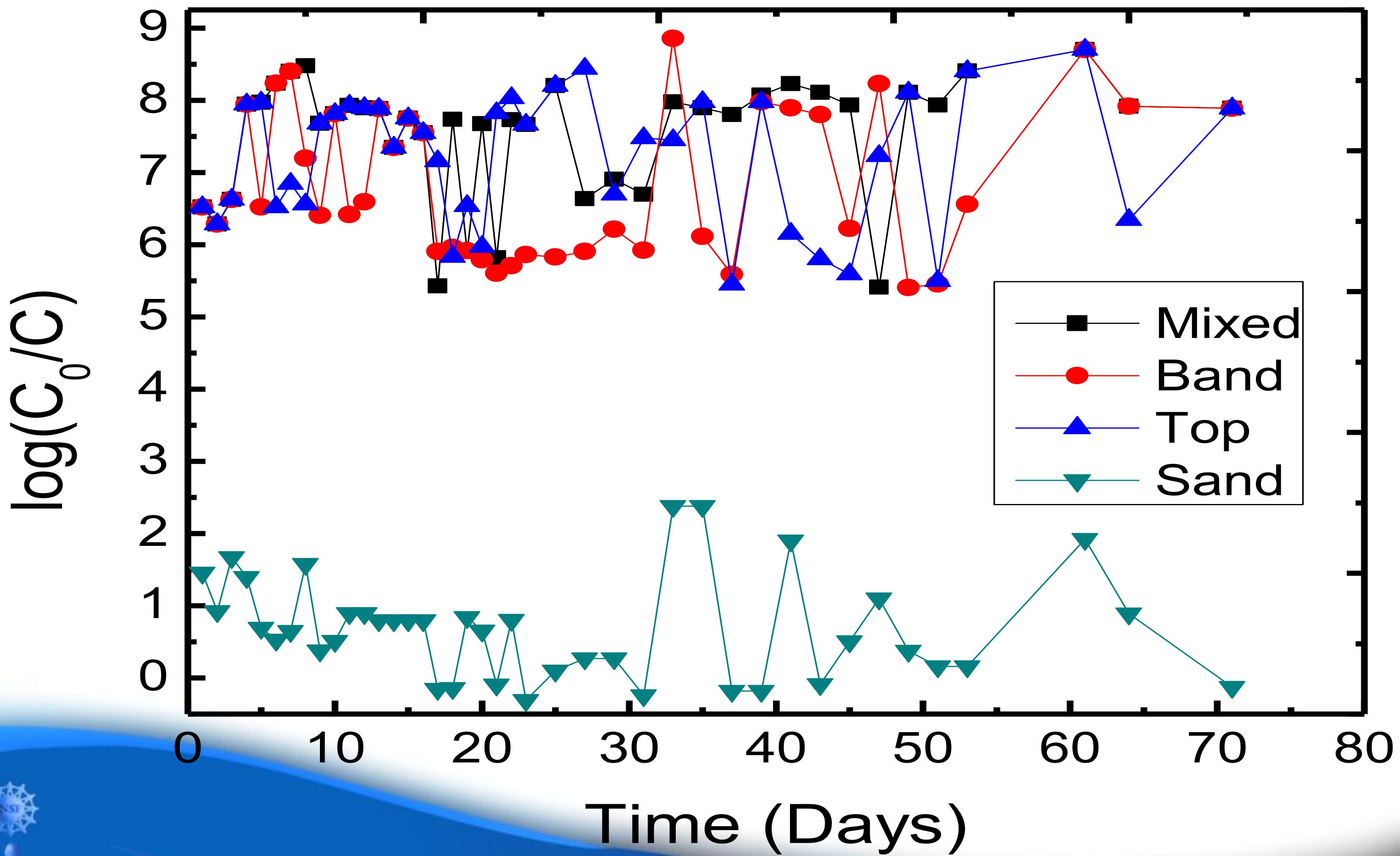


- 1 pore volume (PV) charge
- Aquifer water, MS2
- Primary effluent (PE) added for biofilm growth
- Samples taken every 24 hours

Daily Charged Columns



1 PV, Daily
Charged Columns



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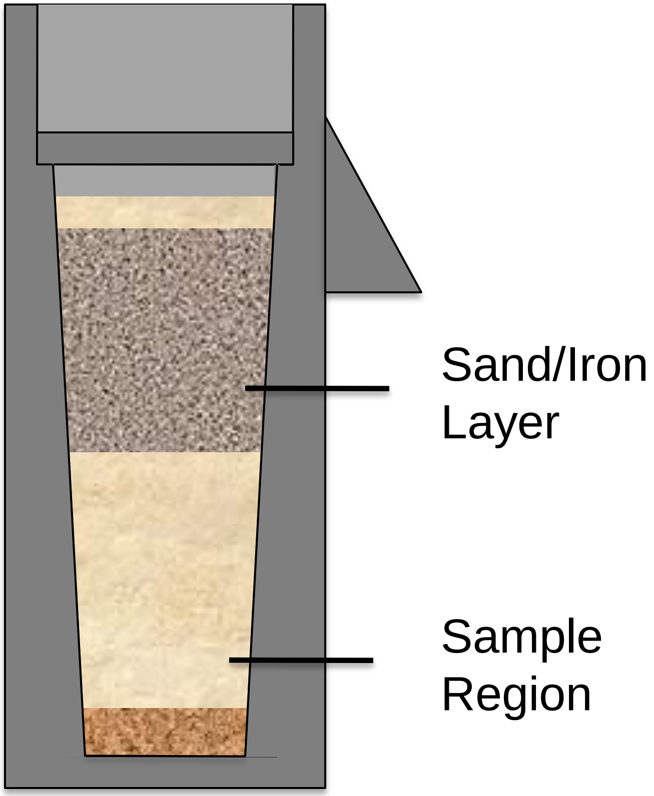
Total Organic Carbon

- "Top" orientation used to simulate BSFs with iron in the diffuser basins
- Influent TOC = 3.2 mg/L
- Effluent TOC
  - Mixed = 2.6 mg/L
  - Band = 2.9 mg/L
  - Top = 2.7 mg/L
  - Sand = 3.1 mg/L

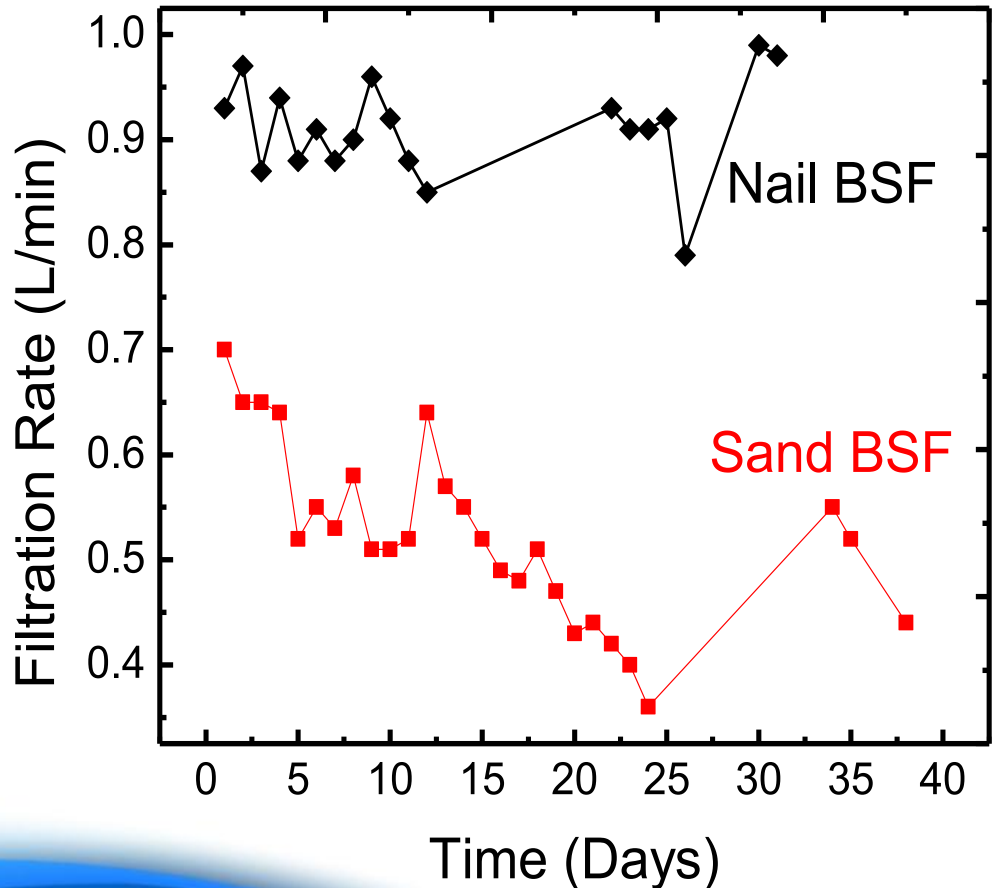
Household-scale Tests



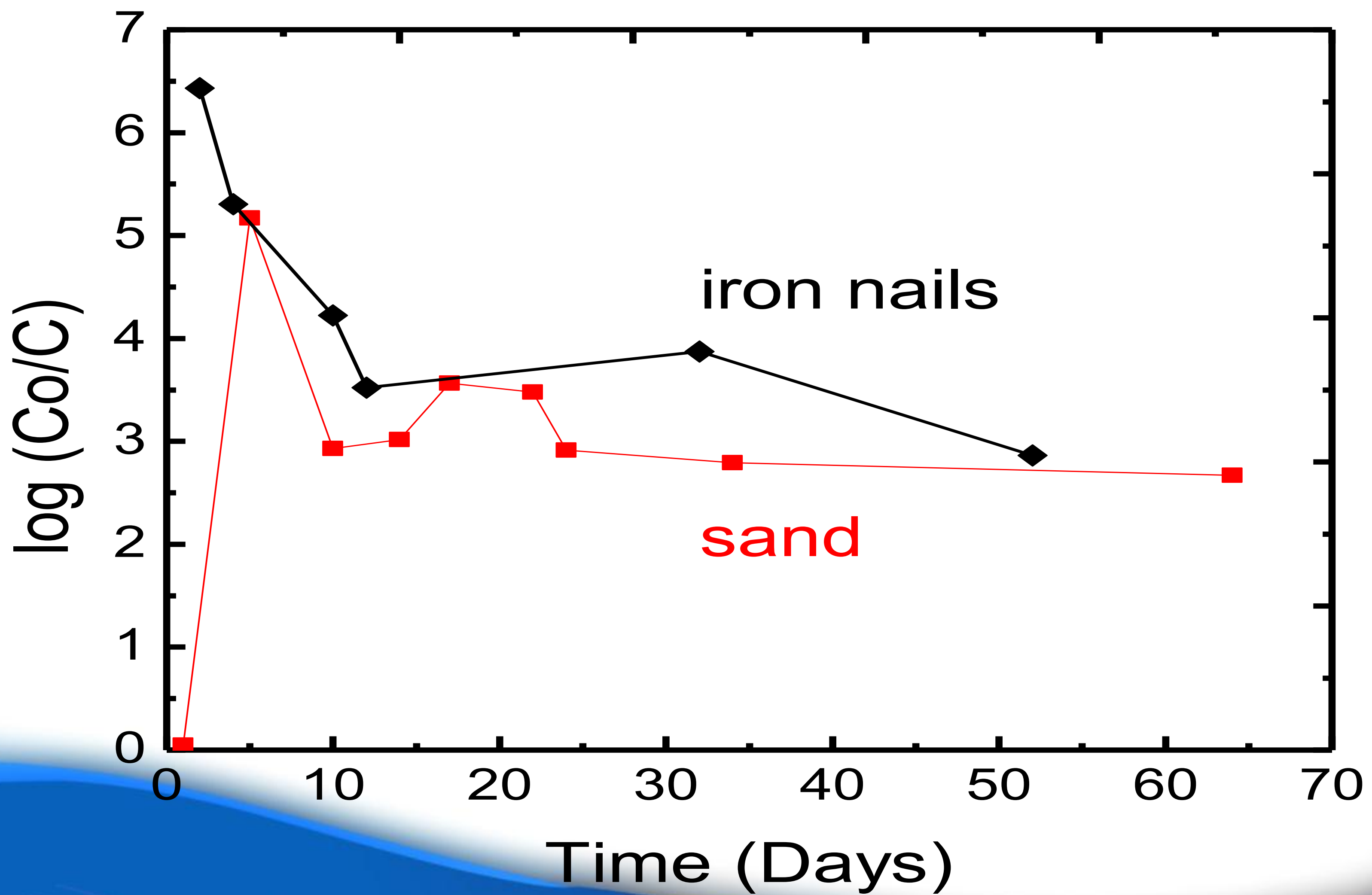
- Iron (10 lbs) mixed evenly throughout the top half of media
- Aquifer water with 2.5% PE
- Samples taken at ~10 minutes

Plastic BSFs

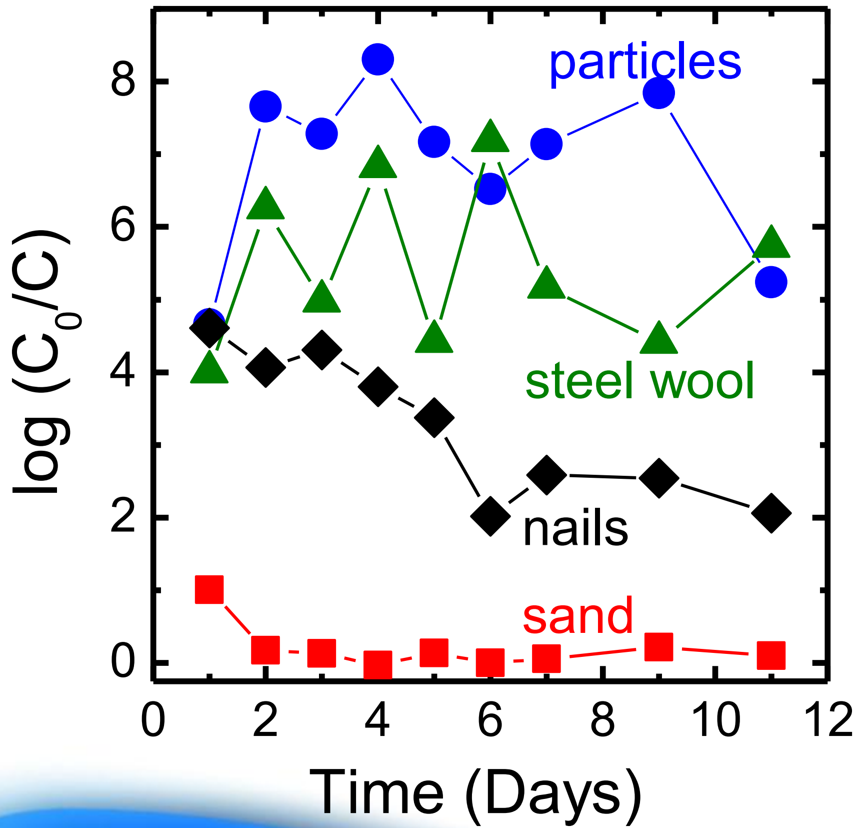
Plastic BSFs: Flow rate



Plastic BSFs: MS2 Removal



Alternative Materials

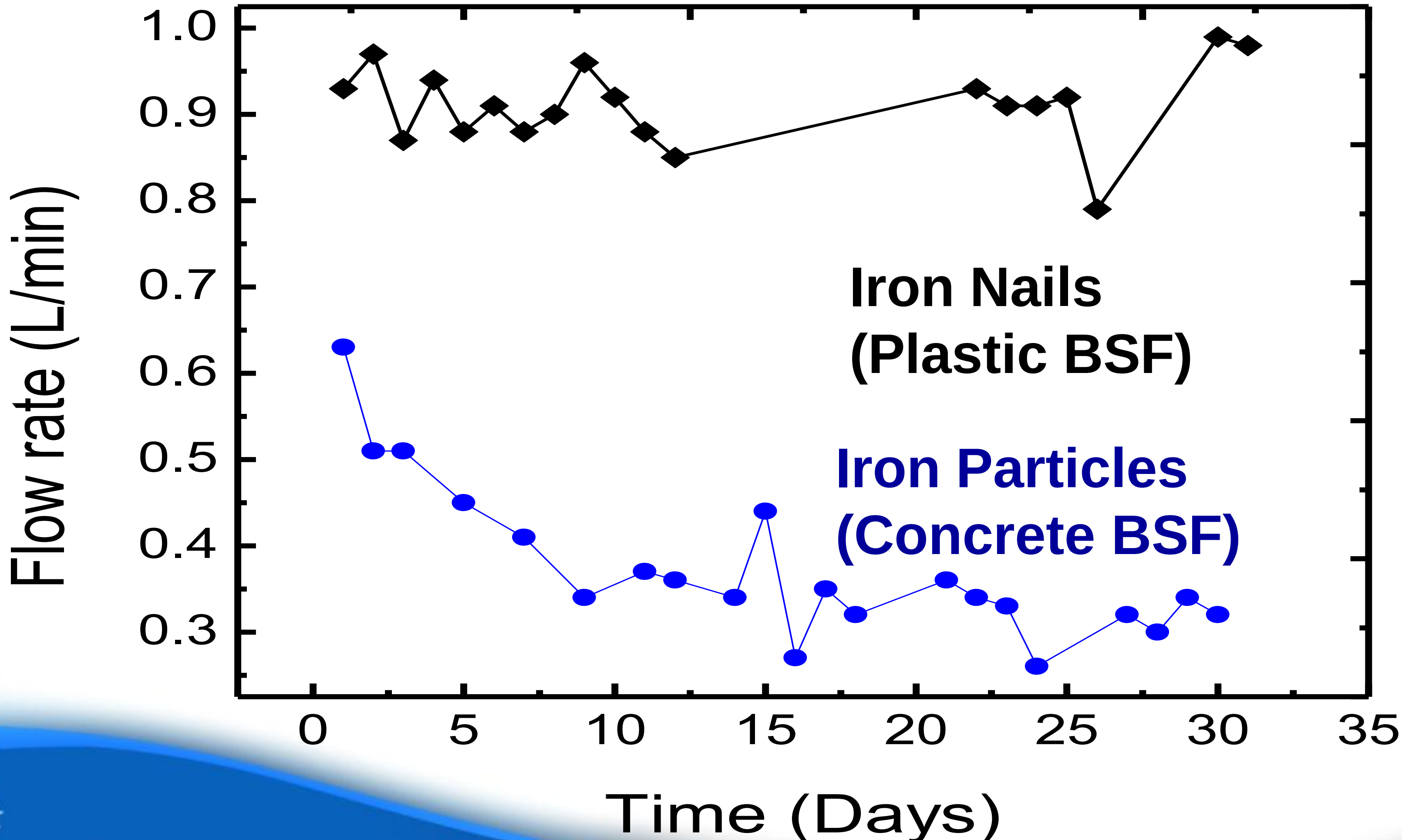


- New materials needed
  - Steel wool
  - Iron particles
  - Smaller nails
- 1 PV, daily charged columns

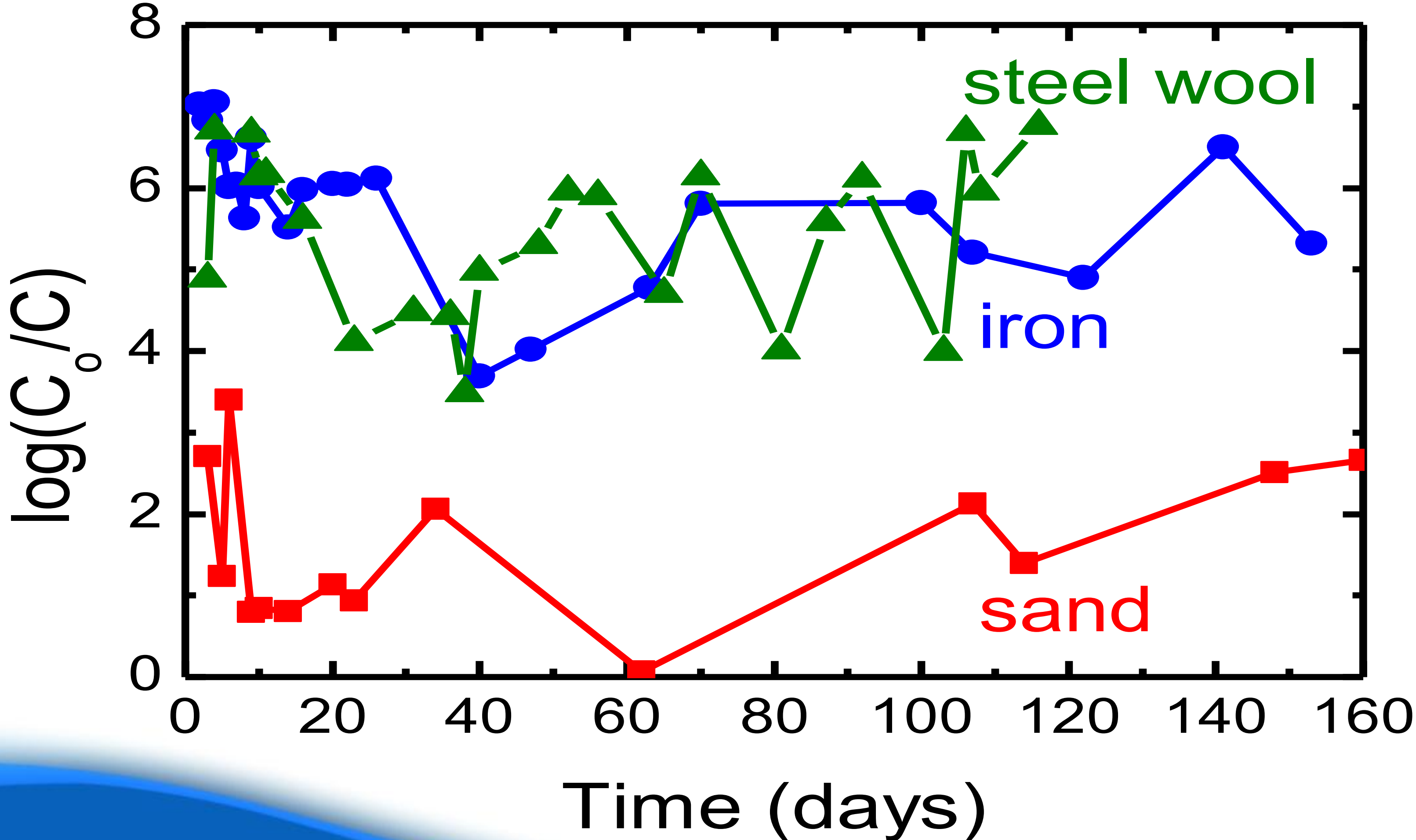
Concrete Biosand Filters

- Repeated experiments using version 9 concrete BSF's
  - Sand Only
  - Iron Particles
  - Steel Wool

Concrete BSFs: Flow rate



Concrete BSFs: MS2 Removal



Concrete BSFs: Additional Tests

- Dissolved oxygen (DO) 2-6 mg/L in effluent
- Soluble Iron below limit of quantification
- Nitrate levels < 1mg/L
- pH, alkalinity, DO, turbidity, chloride, nitrate samples all taken daily

Design Conclusions

- Addition of iron to the sand media of a BSF provides:
  - Economical water treatment (Steel wool - $2.63 US)
  - Simple design utilizing existing technology
  - Effective virus removal (4-6 log)

Design Benefits

- Local, sustainable materials in place of chlorination
- Cheap, readily available construction materials
- Local labor and knowledge

Future Work

Funded by EPA P3 Phase 2 Award ($75,000)

- Longevity
- On-site research
- In-depth Version 10 study
- Human enteric viruses

On-site Research

- Steel wool and control BSFs
  - Coliform tests
  - MS2 removal
  - *E. coli* removal

- Universidad del Valle de Guatemala

Version 10

- In-depth study at the University of Illinois
  - Removal using recommended guidelines
  - Varying pause periods
  - Varying charge volumes
  - Studying removal mechanisms

Rotavirus

- Small scale experiments
- “Sand” and “Mixed” orientations
- 1 PV charge, samples taken 24 hours later

Conclusions

- Iron Amended BSFs are:
  - Affordable and effective
  - Easy to implement using existing BSFs

- GOAL Program will:
  - Continue to be funded for at least two years
  - Research on-site in Guatemala
  - Focus on emerging technology and relevant issues

Q&A

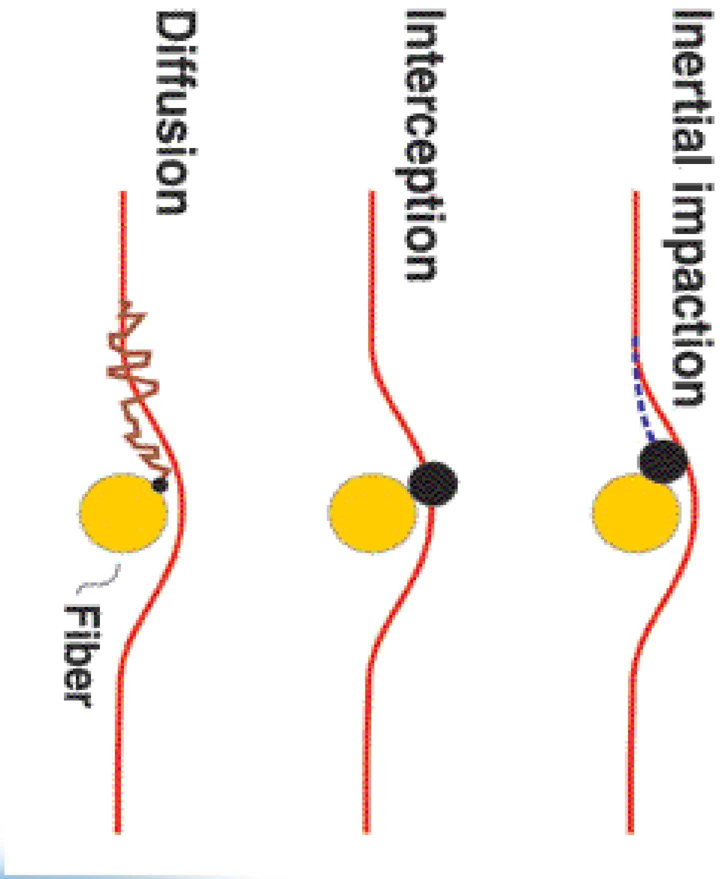
Questions?



Appendix



Filtration Mechanisms



- Brownian Motion

$$\eta_B = 0.9\left(\frac{\kappa T}{\mu d_p d_s V}\right)^{2/3}$$

- Interception

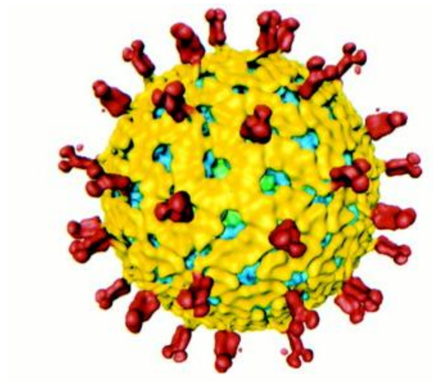
$$\eta_I = \frac{3}{2}\left(\frac{d_p}{d_s}\right)^2$$

- Sedimentation

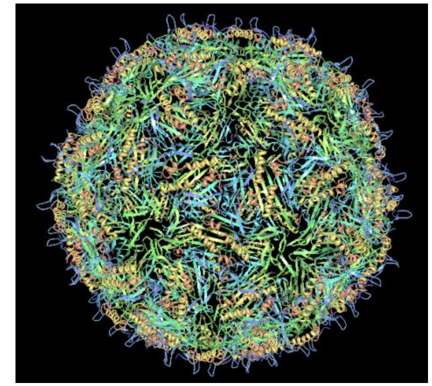
$$\eta_S = \frac{g(\rho_p - \rho_w)d_p{}^2}{18\mu V}$$

cdc.gov

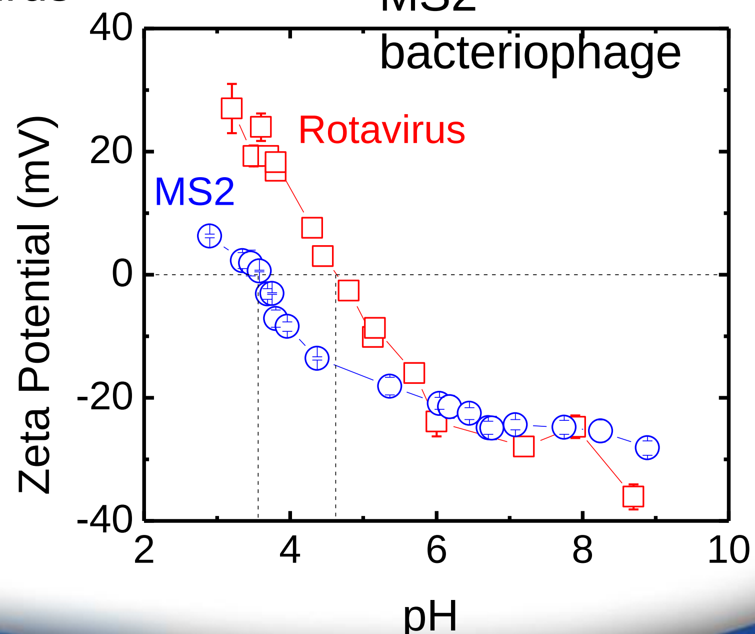
Model Viruses



Rotavirus



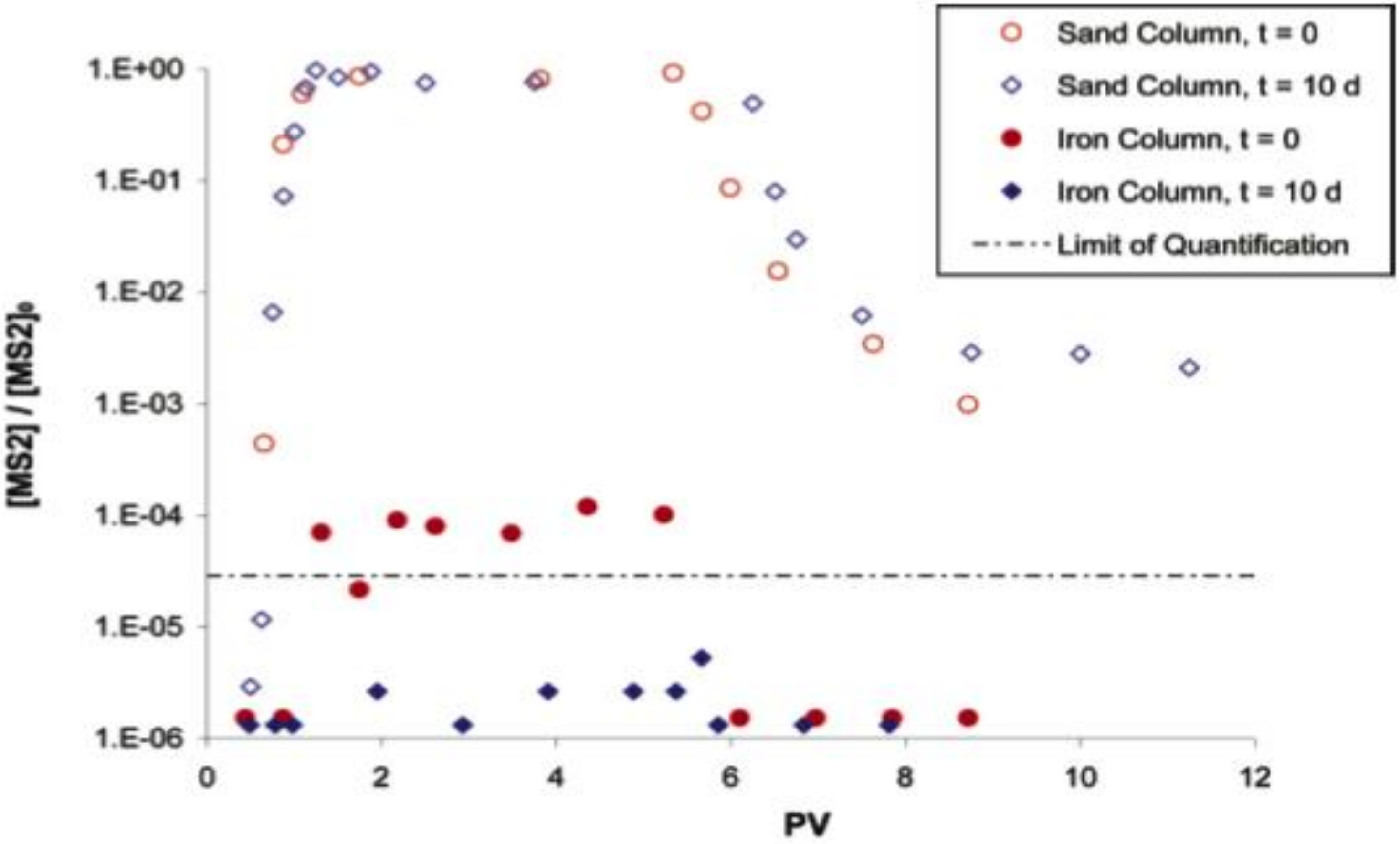
MS2 bacteriophage



- Rotavirus hospitalizes 55,000 children in USA and kills 600,000 worldwide annually

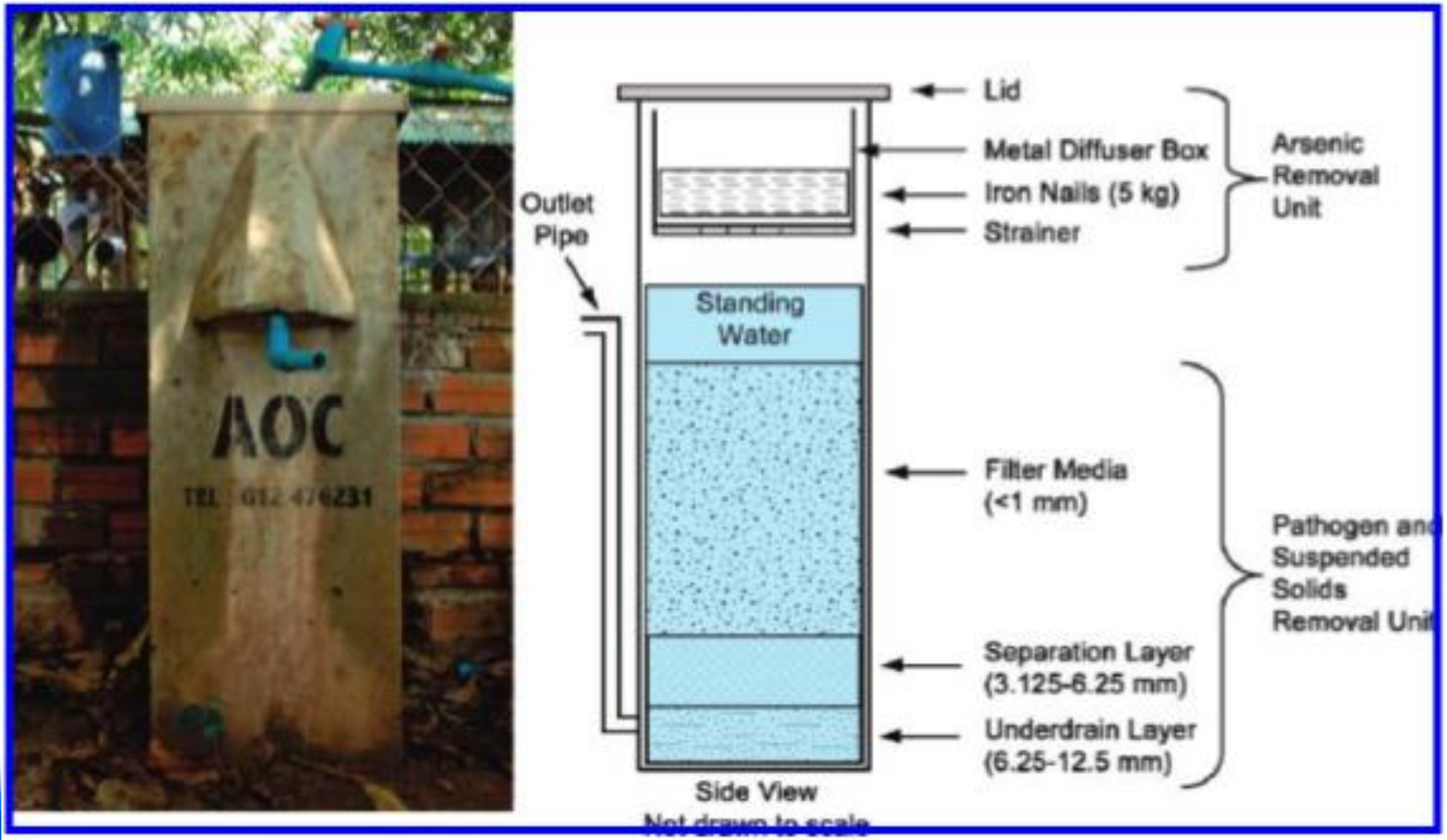
(Parashar et al., 2006, Emerging Infectious Diseases).

Iron Oxide Regeneration



You, Y.W., J. Han, P.C. Chiu, and Y. Jin, Removal and Inactivation of Waterborne Viruses Using Zerovalent Iron. Environmental Science & Technology, 2005. 39(23): p. 9263-9269.

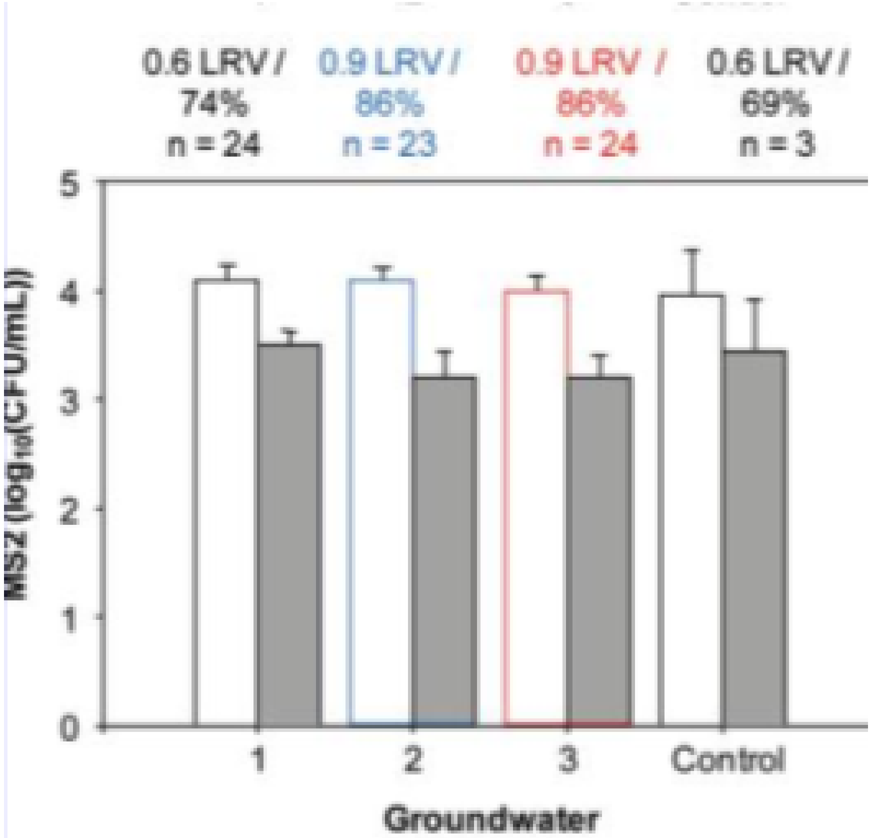
BSF's with Iron in the Diffuser Basin



Chiew, H, et al. "Effect of Groundwater Iron and Phosphate on the Efficacy of Arsenic Removal by Iron-Amended BioSand Filters." Environmental Science & Technology 2009 43 (16), 6295-6300

MS2 removal from Iron-Amended BSF's

- MS-2 removal is indistinguishable from control
  - influent = white bars
  - effluent = gray bars
- Minimal removal due to short contact time with iron in diffuser
- To increase the contact time, the iron material should be moved to the sand media



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