Biological Filtration – do the benefits outweigh the risks?

Lynn Williams

PNWS-AWWA Conference

May 6, 2011

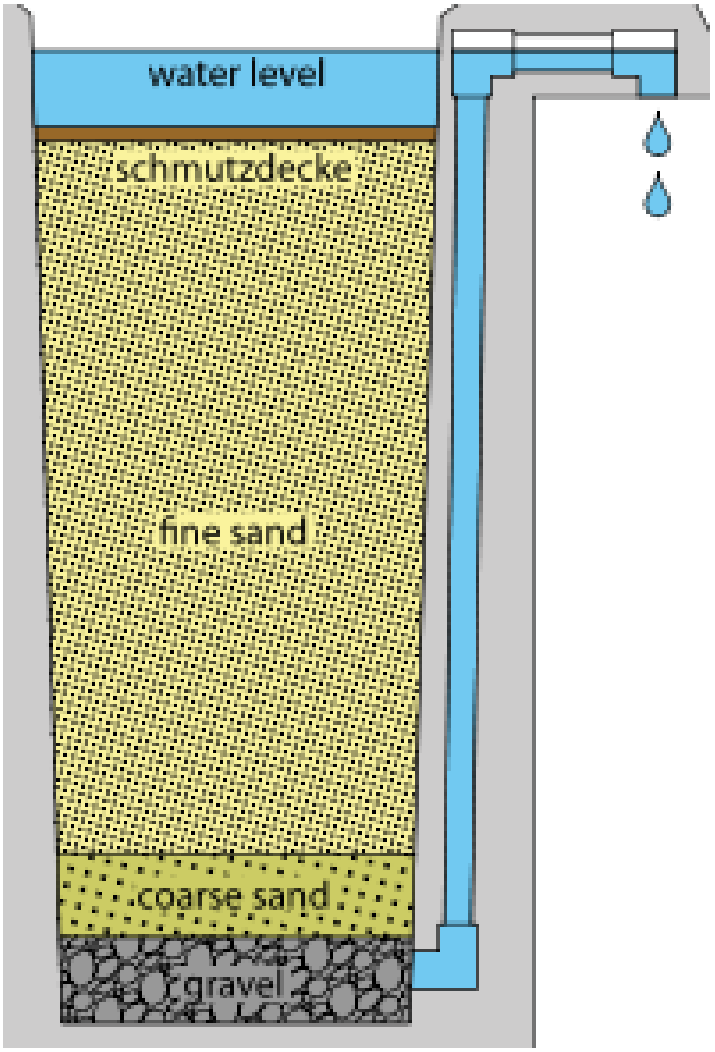
Brown AND Caldwell

Presentation Roadmap

- Overview
  - Types of biological filtration
  - Benefits
  - Potential risks
- Case study: bench-scale assessment of biological filtration for groundwater treatment with carbon and phosphate addition
- Conclusions

Slow Sand Biological Filtration

- Historically, biological filtration around for 100's of years via slow sand filtration
  - Biofilm layer "*Schmutzdecke*"
- Relies on microbial activity of bacteria to degrade contaminants



Example of Slow Sand Filtration

Rapid Sand Biological Filtration aka BAF

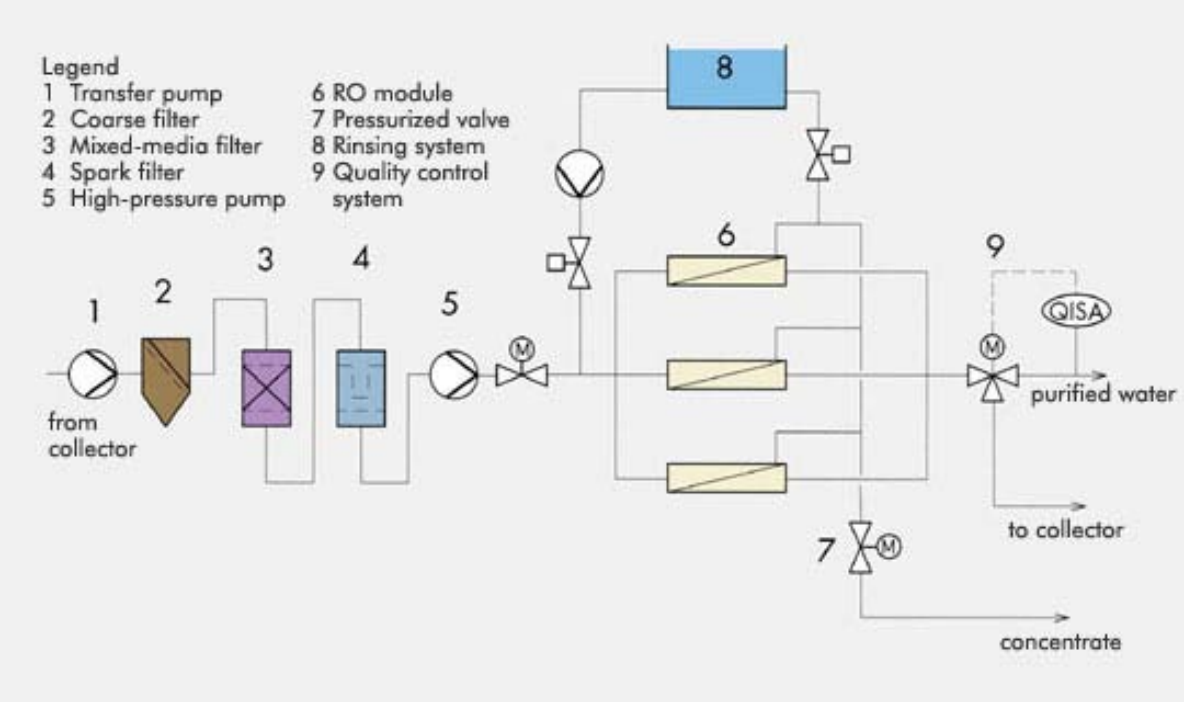
- Passive: Filters become biologically active when a disinfectant residual is not maintained across the filter
- A NEW TAKE
- Active: Enhance biological activity through
  - GAC media to increase surface area for biomass (BAC)
  - Ozonation prior to filtration to promote biological oxidation of contaminants
  - External phosphorus addition
  - External carbon addition

Renewed Interest in Biological Filtration

- 2011 PNWS-AWWA
  - Chance Lauderdale – Engineered Biofiltration
- AWWA Biological Drinking Water Treatment Committee
- IWA Leading Edge Technology Conference, Phoenix, AZ, June 2010 – Workshop on biological drinking water treatment
- 2009 WQTC – Two sessions on biological drinking water treatment

Biological Filtration Benefits

- Green technology (natural)
  - Minimize chemical addition and residual waste
  - Reduces contaminants to innocuous end-products



Biological Filtration Benefits

- Removal of multiple organic/inorganic contaminants
  - Dissolved organic matter
  - Taste and odor compounds
  - Disinfection by-products
  - Emerging contaminants of concern
  - Perchlorate
  - Nitrate
  - Ammonia

Biological Filtration Benefits

- Removal of multiple organic/inorganic contaminants
  - Dissolved organic matter
  - Taste and odor compounds
  - Disinfection by-products
  - Emerging contaminants of concern
  - Ammonia
  - Perchlorate
  - Nitrate

→ Groundwater treatment

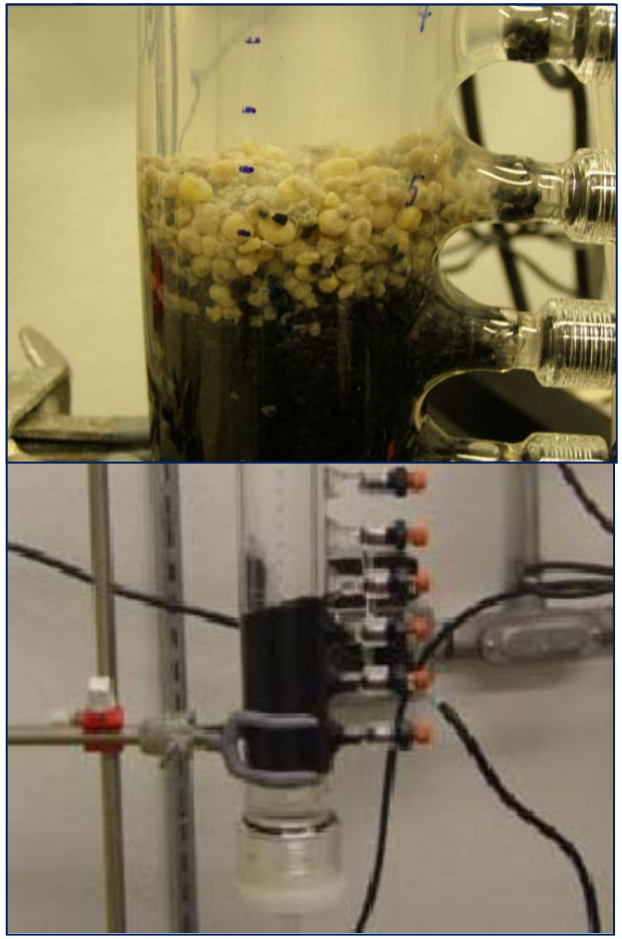
Potential risks?

- Promoting bacteria in drinking water treatment plant
- Potential concerns
  - Is there a greater risk for microbial pathogens in finished water?
  - Reduced headloss due to biomass accumulation
  - Reduced UFRVs

Bench-scale Study – BAC

Dr. Lutgarde Raskin (University of Michigan), Dr. Xu Li (University of Nebraska)

- Seeded with biomass from GAC filters from surface water and groundwater WTPs
- Treatment of synthetic groundwater
- Microbial reduction of perchlorate (ClO_4^-) and nitrate (NO_3^-)
- Acetic acid added as electron donor or carbon source
- Ran side-by-side with pilot-scale plant in Rialto, CA
- EBCT = 20 min

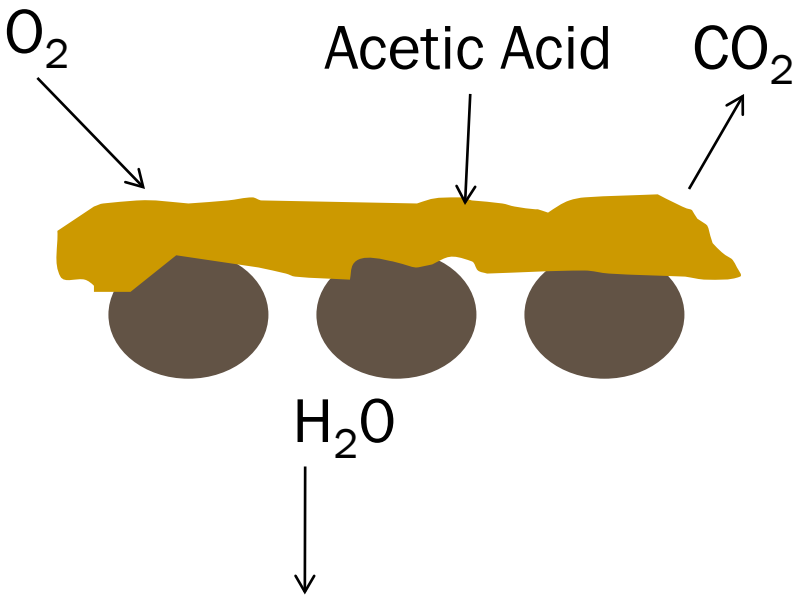


Regulations

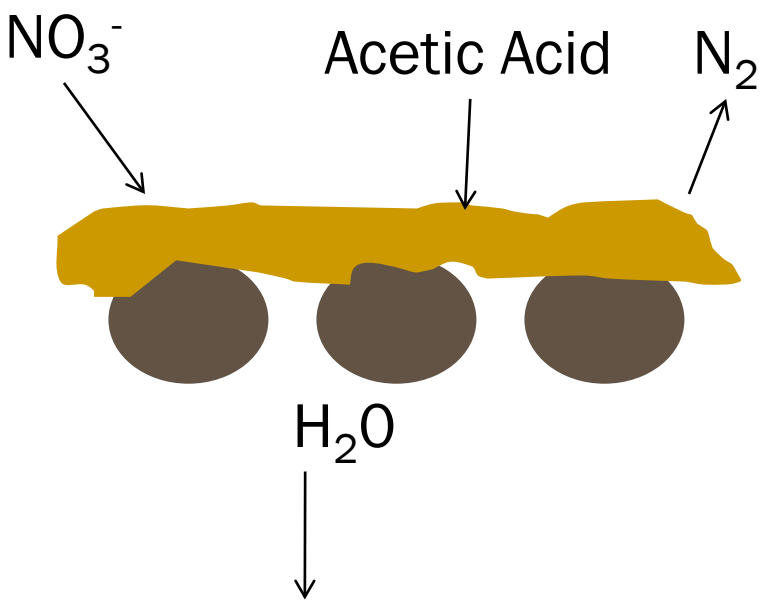
- Perchlorate, ClO_4^-
  - Toxicity: disturbs the function of the thyroid
  - Sources: natural and human influence
    - primary ingredient in solid propellant for rockets, missiles, and fireworks
  - As of 2005, found in 153 public water systems in 26 states
  - EPA considering perchlorate standards for at least 9 years
    - CA current standard – 6 micrograms per liter (ug/L)
    - Looking at lowering limit to 1 ug/L

- Nitrate
  - Toxicity: infants below the age of 6 months - blue baby syndrome
  - Standard: 10 mg/L

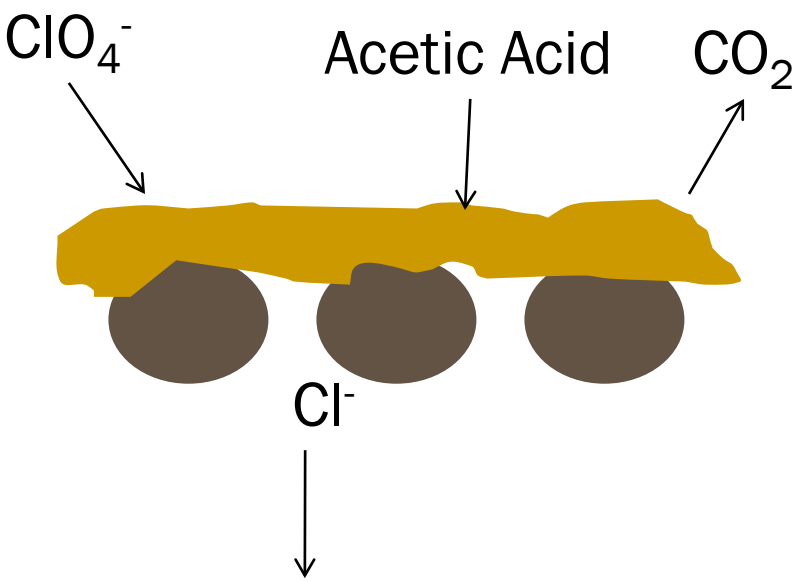
Microbial Oxidation of Nitrate and Perchlorate

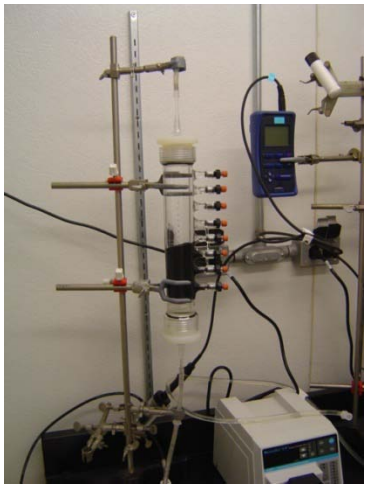


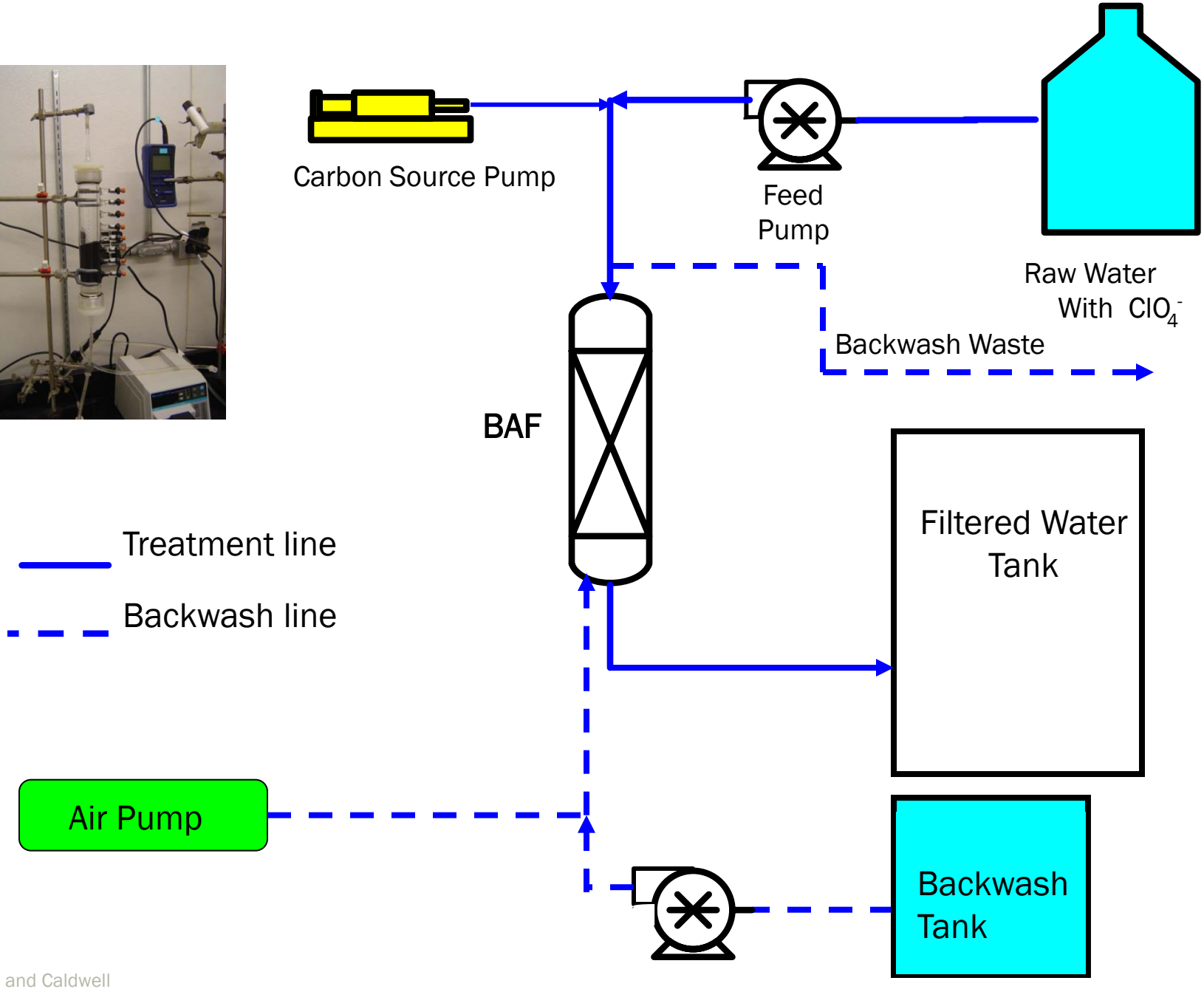
Microbial Oxidation of Nitrate and Perchlorate



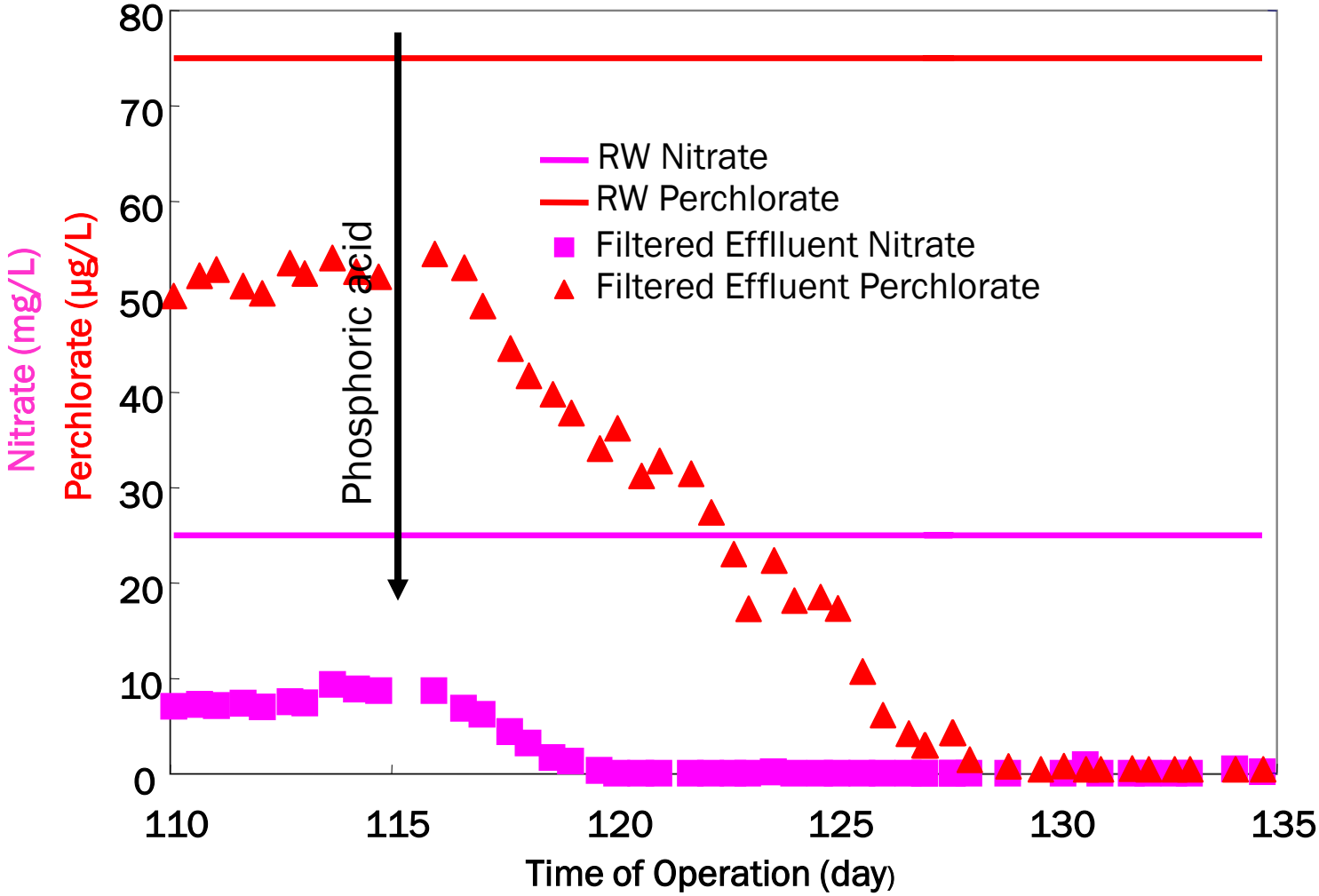
Microbial Oxidation of Nitrate and Perchlorate





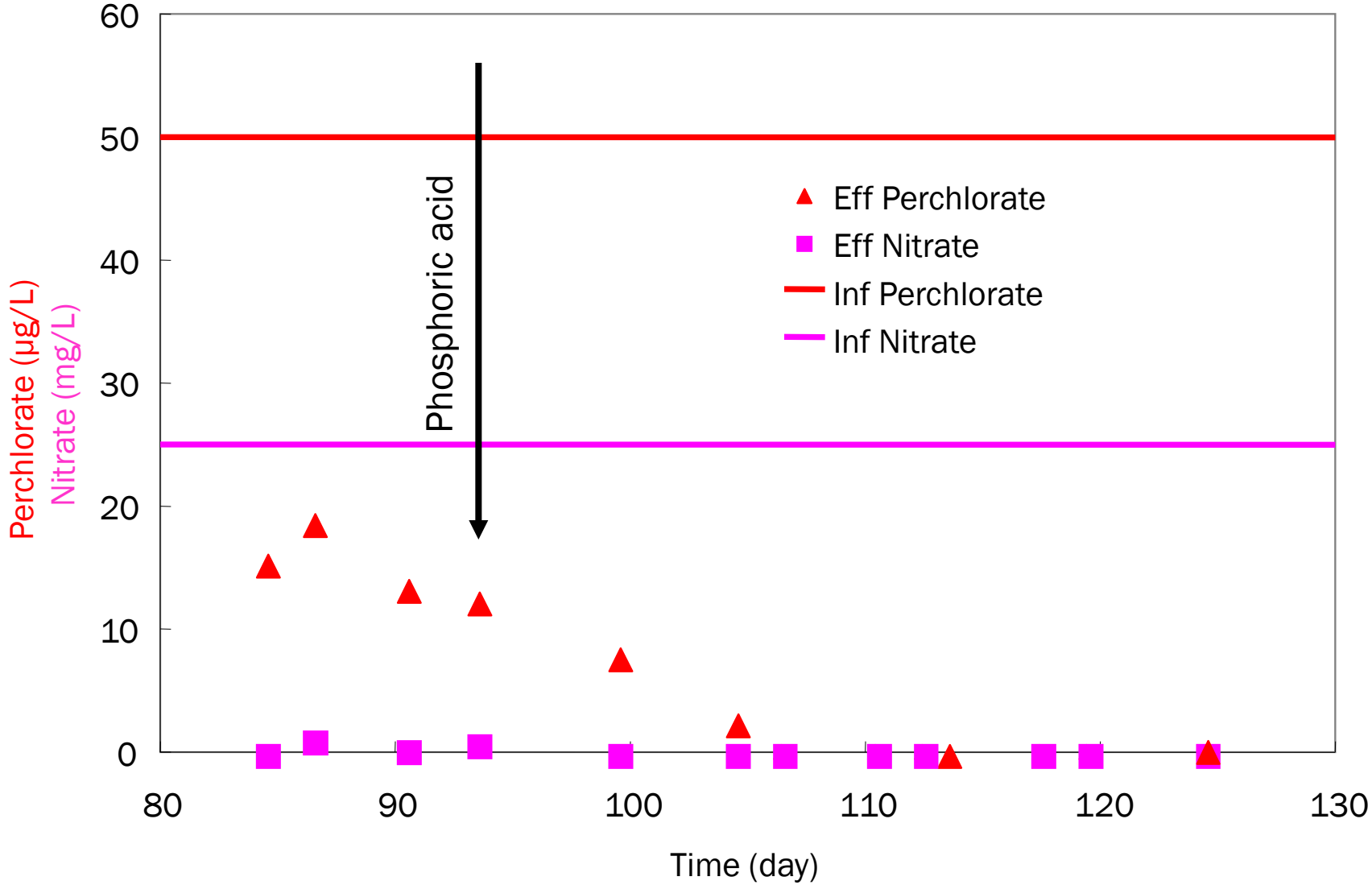

Carbon Source Pump
Feed Pump
Raw Water With ClO_4^-
Backwash Waste
BAF
Filtered Water Tank
Treatment line
Backwash line
Air Pump
Backwash Tank

Perchlorate and Nitrate Results: Bench-scale



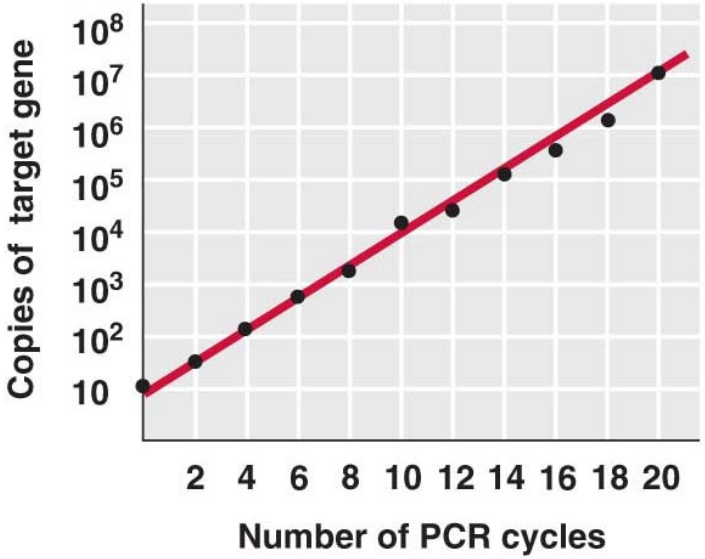
145 ug/L of phosphoric acid

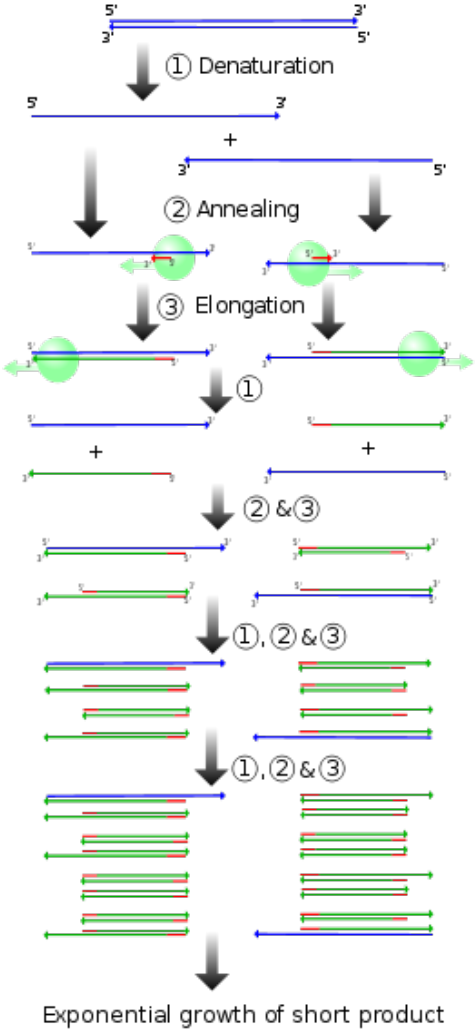
Perchlorate and Nitrate Results: Pilot-scale



Real-time Quantitative PCR

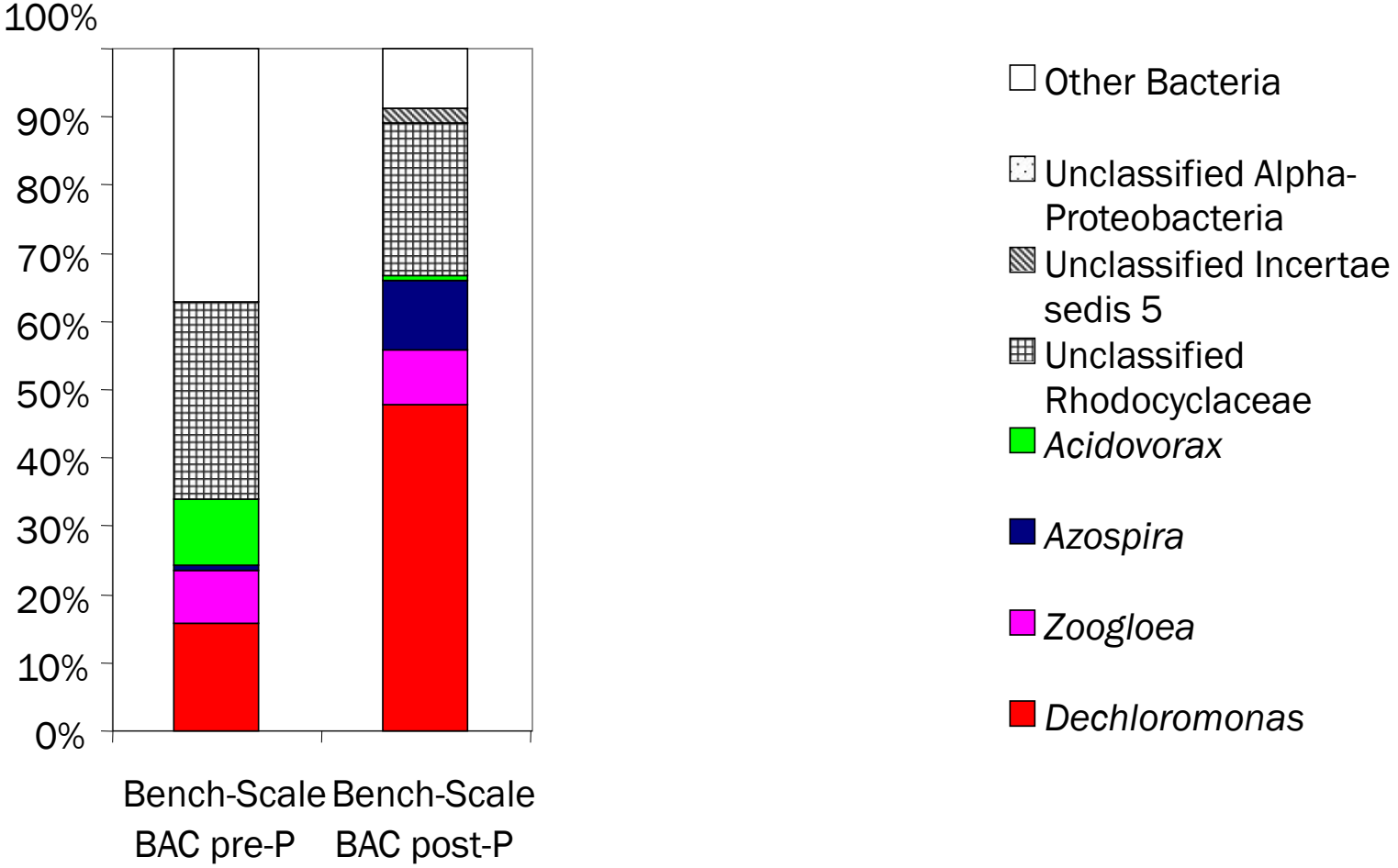
- 16S rRNA gene
- General bacterial primers
- PCR products sequenced for identification



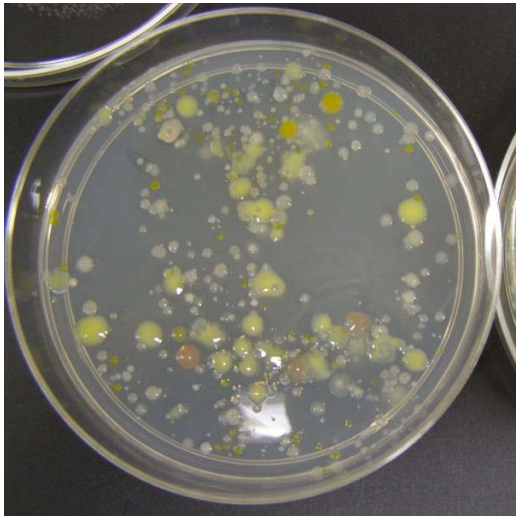


Characterization of Microbial Community

Conclusion: Microbial population will shift if given the environmental conditions.



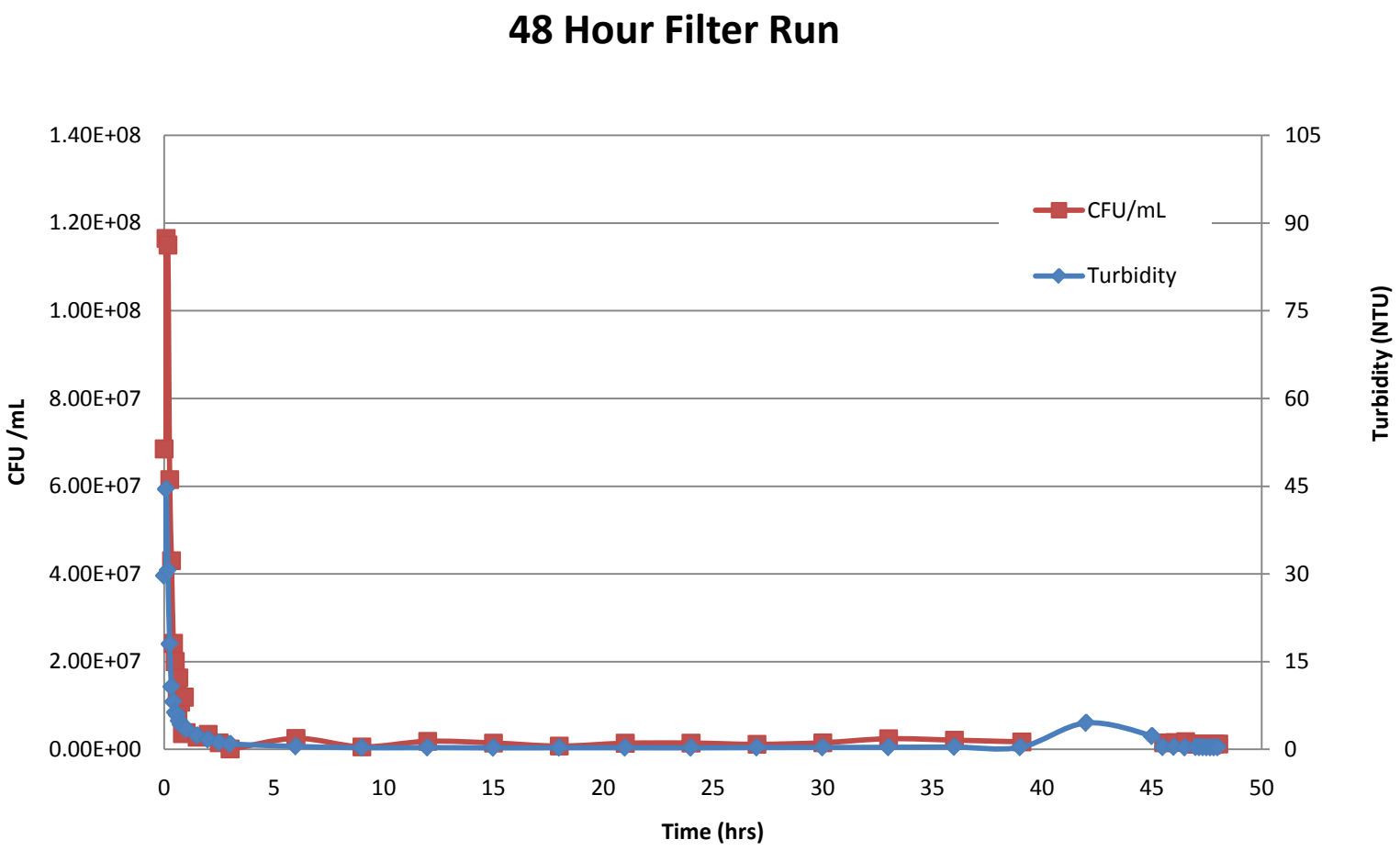
Existing Regulations



HPC

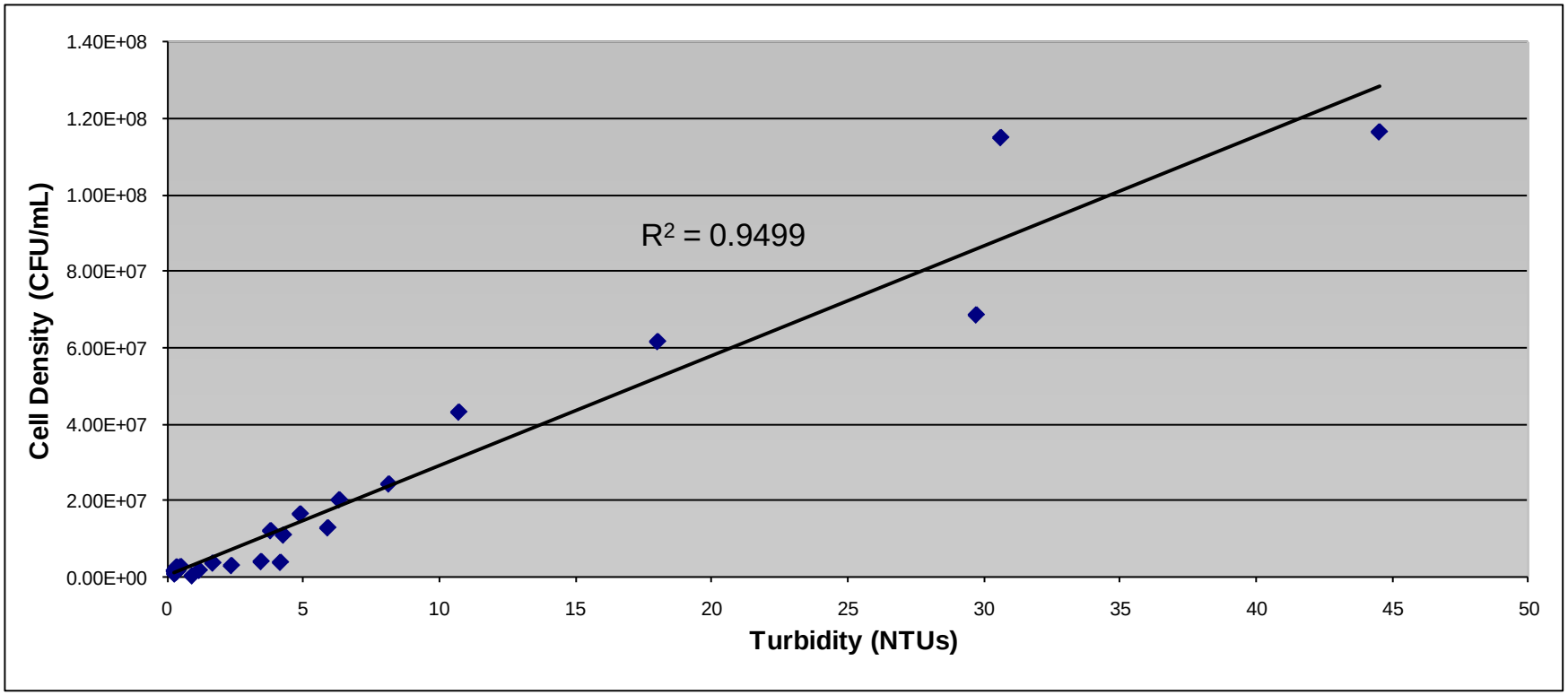
- Turbidity
  - Conventional or direct filtration
  - Not exceed 1 NTU
  - Less than 0.3 NTU, 95% of monthly samples
- Heterotrophic plate count (HPC): No more than 500 bacterial colony forming units (CFU) per mL
- Total coliforms
  - *No more than 5.0% samples total coliform-positive in a month*

Examination of Filtered Water



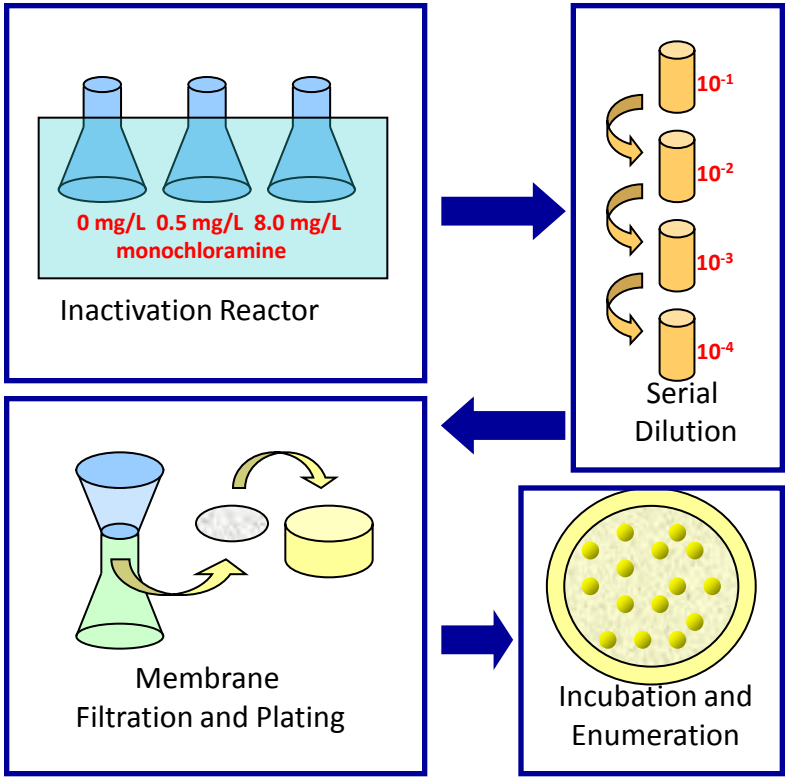
Strong Correlation between Turbidity and Cell Density

- Turbidity can be used as a quick indicator

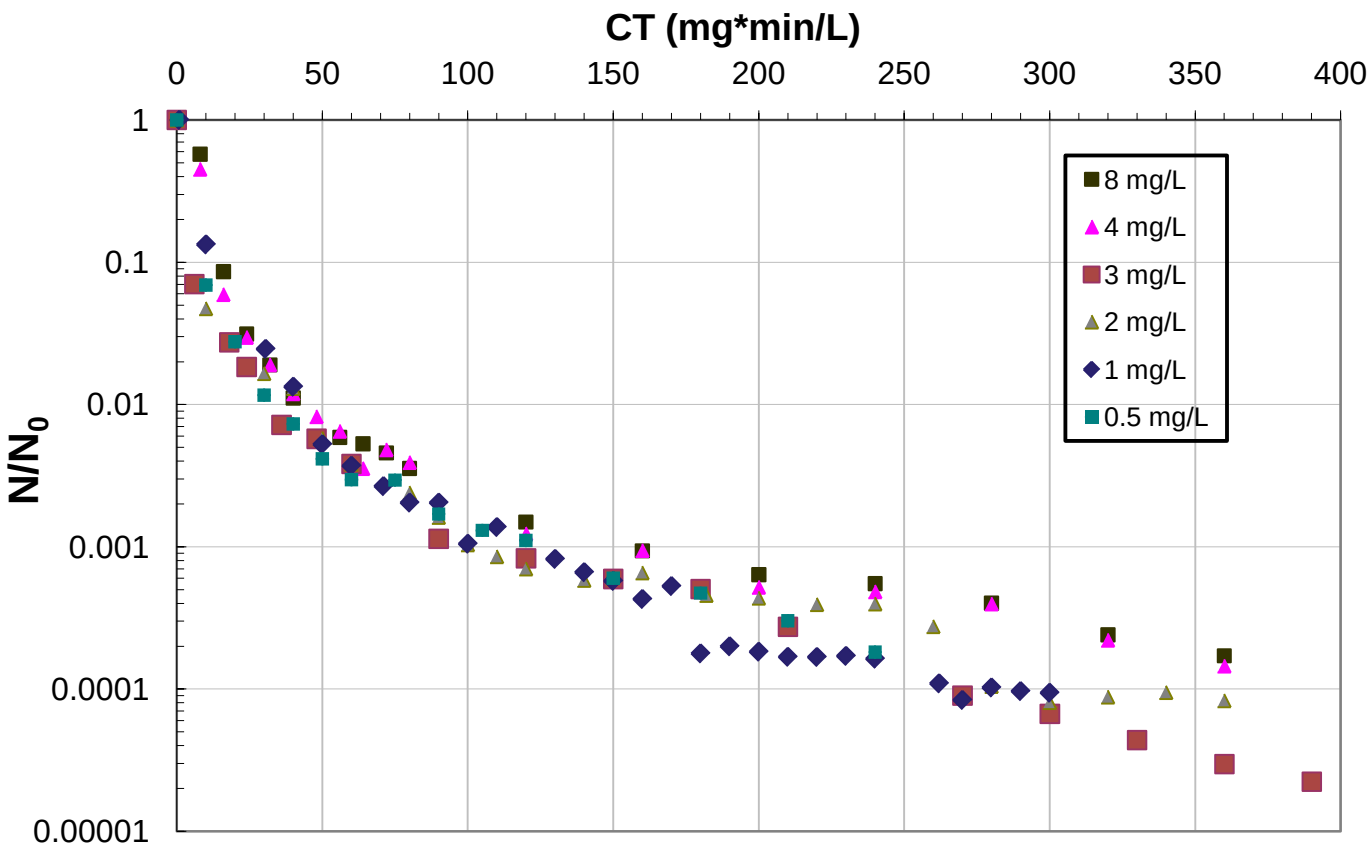


Disinfection Experiments

- Collect BAC reactor effluent samples 5 min after backwash
- Inactivation with monochloramine in batch reactors
- Dose ranged from 0.5-8 mg/L
- pH 8, 20^{0}C
- HPC using R2A agar

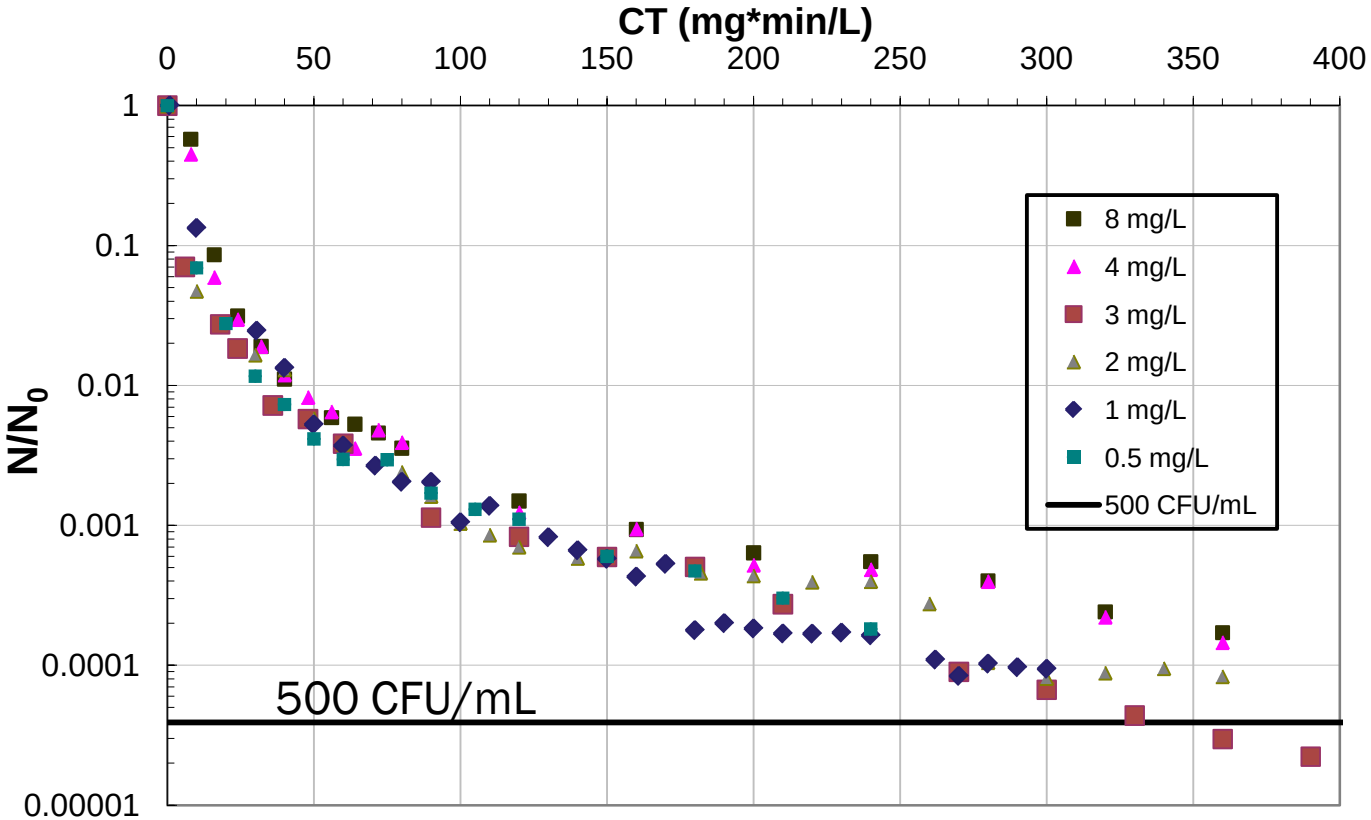


Disinfection Results



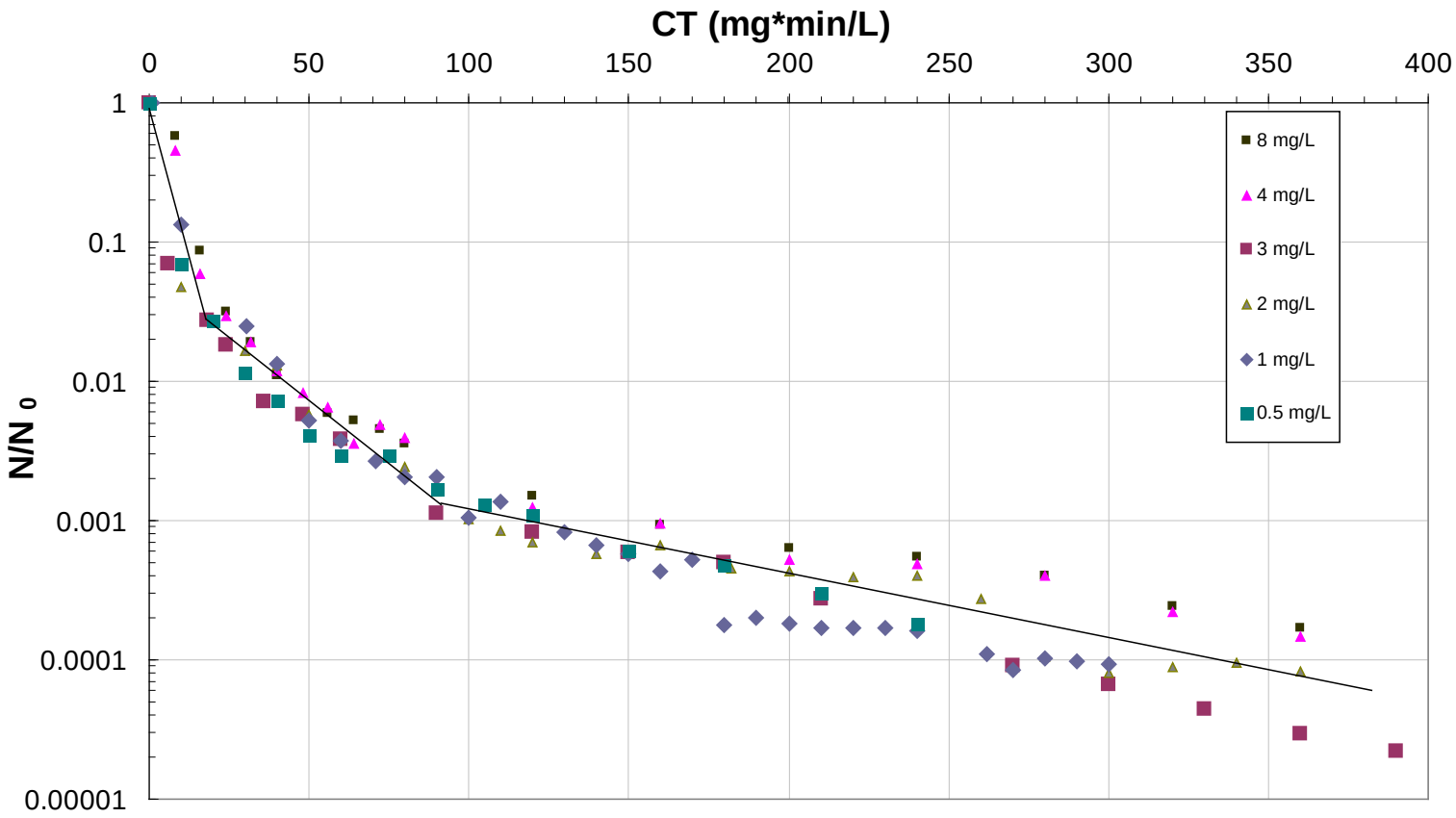
- Experiments followed CT rule

Disinfection Results



- Experiments followed CT rule
- Monochloramine of 3 mg/L and CT value of at least 350 mg-min/L

Disinfection Results



- Fast rate of inactivation ensued by two lower inactivation rates

Modeling of Inactivation Kinetics

- Equation to characterize CT:

Chick Watson Equation

$$\frac{N}{N_0} = e^{-kCT}$$

Modified Chick Watson Equation

$$\frac{N}{N_0} = \frac{N_1}{N_0} e^{-k_1 CT} + \frac{N_2}{N_0} e^{-k_2 CT} + \frac{N_3}{N_0} e^{-k_3 CT}$$

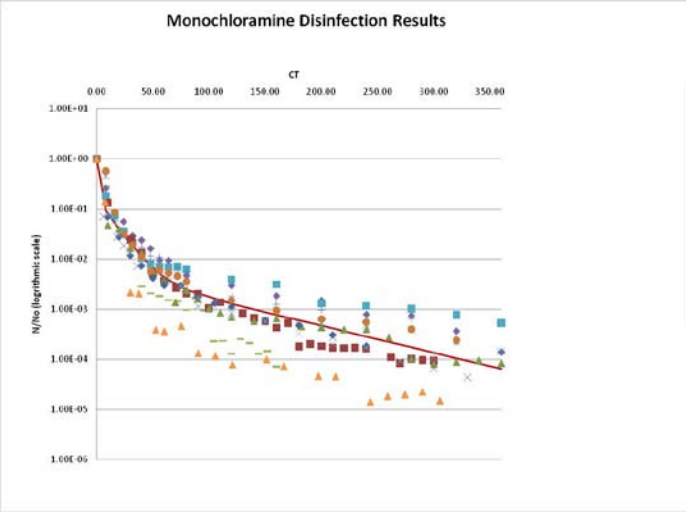
Two or Three Population Model

Vicuña-Reyes, P., J. Luh, and B. Marinas. 2007. Inactivation of *Mycobacterium avium* with chlorine dioxide.Water Res. 42: 6-7

Modeling of Inactivation Kinetics

- Using Three Population Model solved for decay constants

N1,0/N0	0.849
N2,0/N0	0.152
N3,0/N0	0.006
k1	-0.597
k2	-0.074
k3	-0.012
Variance	0.009



	Chloramine CT Value (mg/L-min) @ 20 °C, pH 6-9		
	Based on EPA CT Tables (Aug. 1999)		BAC Reactor
Inactivation log	Giardia	Viruses	Heterotrophic Bacteria
3-log	1,100	534	160
500 HPC			350

Conclusions – Rapid Sand Biological Filtration with Carbon and Phosphate Addition

- Filter removed perchlorate and nitrate far below MCLs with phosphate addition
- Achieved 500 HPC requirement using a CT of 350 with monochloramine
  - Recommend sand layer if designing GAC reactor
- Recommend WTP performs pilot testing before implementing full-scale
  - Determine optimal dosages for microbial community
  - Better understanding of backwash procedures
- First US plant to treat perchlorate/nitrate contaminanted water biologically
  - Plant being built by Envirogen Technologies in collaboration with West Valley Water District and the City of Rialto
  - 3 mgd

Do the benefits of biological filtration outweigh the risk?

- Yes
- Mitigate risk
  - Adequate disinfection
  - Manage bacteria breakthrough
- Promotion of biological activity
  - Remove organic and inorganic contaminants
  - Get a secondary removal mechanism out of filtration

Acknowledgements and References

- Raskin Research Group and Dr. Xu Li (University of Nebraska)

  - Li, X, G. Upadhyaya, W. Yuen, J. Brown, E. Morgenroth, and L. Raskin. 2010. Changes in Structure and Function of Microbial Communities in Drinking Water Treatment Bioreactors upon Addition of Phosphorus. AEM. 76:22.
  - Williams, L., X. Li, C. Xi, and L. Raskin. An Examination of the Filtrate of a Biologically Activated Carbon Reactor following Monochloromine Disinfection. Water Res. (In preparation).

- U.S. National Science Foundation Biocomplexity GEN-EN Program (Grant No. BES-0412618)

Questions

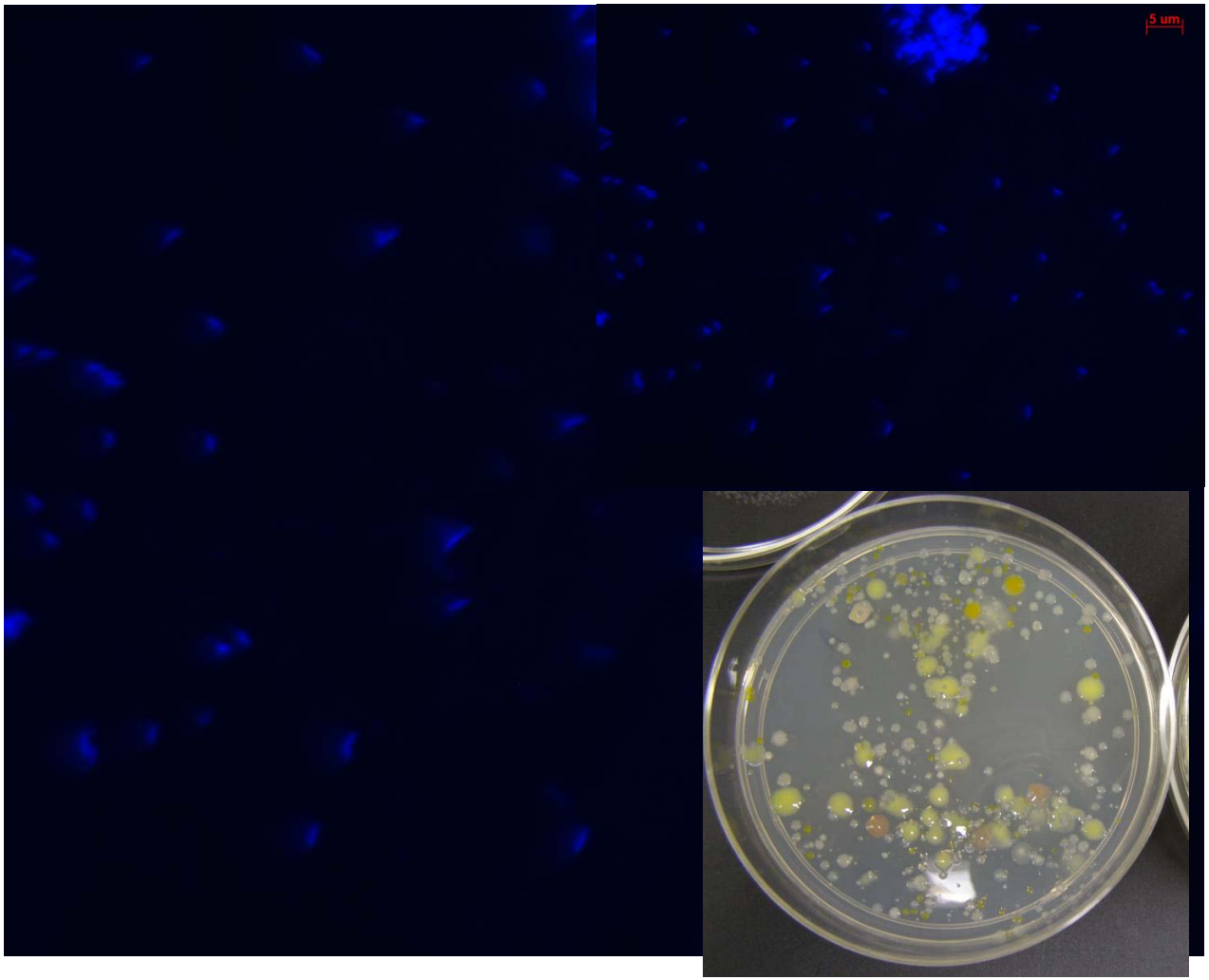
Lynn Williams
lwilliams@brwncald.com
(206) 749-2893

Brown AND Caldwell

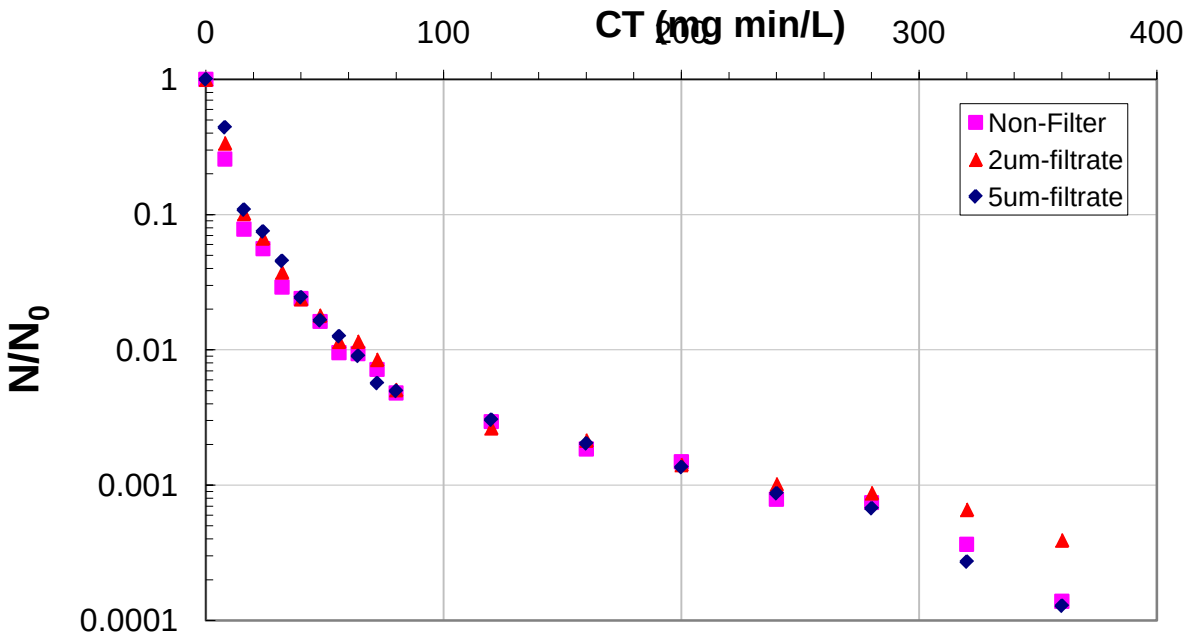
Two hypotheses for slow inactivation phases

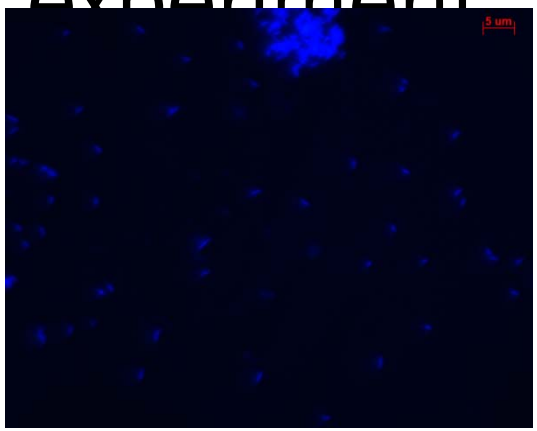
1. Slow diffusion of chloramine into cell aggregates

2. Different bacteria in mixed microbial community respond differently to chloramine inactivation



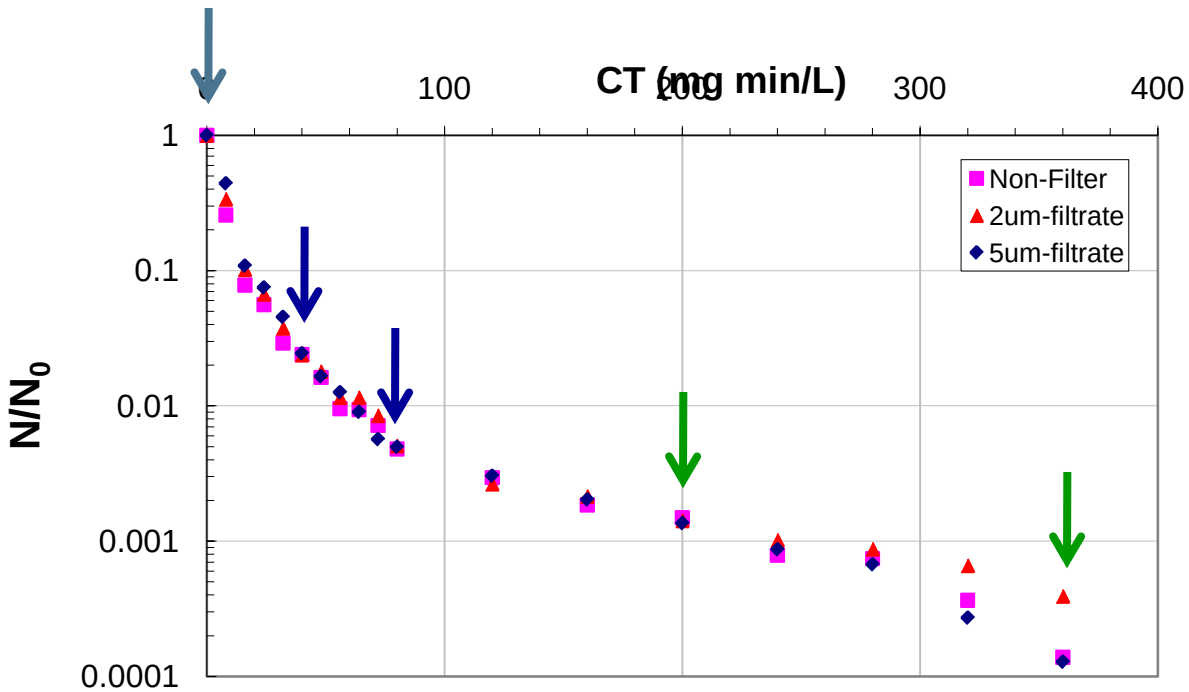
Evaluate hypothesis 1: filtration experiment

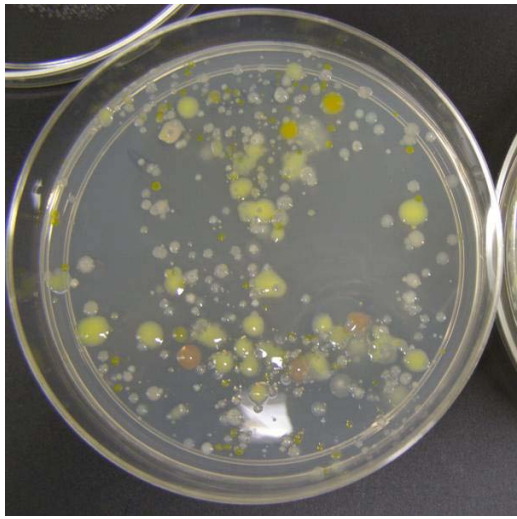




- BAC effluent sample – not filtered, 2-µm filter, 5-µm filter
- Inactivation with 4 mg/L monochloramine
- Inactivation curves for filtered and non-filtered samples overlapped
- Slow diffusion of chloramine into cell aggregates does not explain low rates of inactivation

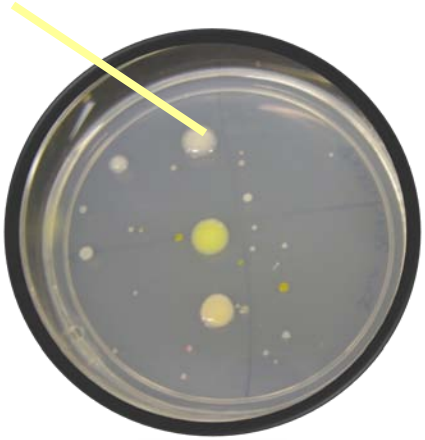
Evaluate hypothesis 2: colony PCR and sequencing

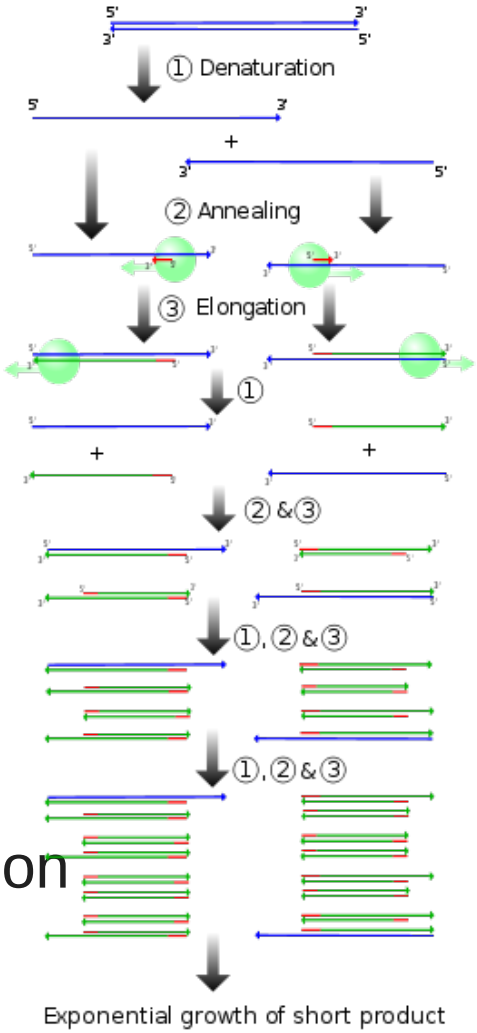




- Colony PCR performed at CT values of 0, 48, 80, 200, and 360 mg min/L

Colony PCR





- Targeting [illegible] ene
- General [illegible] primers
- PCR products were sequenced for identification

Identification of surviving bacteria during inactivation

Bacterial Identification	CT		
	CT 0	CT 48 to 80	CT 200 to 360
Acidovorax spp.	2	4	0
Aminobacter spp.	0	1	3
Bosea spp.	0	5	26
Curvibacter spp.	1	2	0
Dechloromonas spp.	6	0	0
Microbacterium spp.	1	6	6
Novosphingobium spp.	3	9	0
Rhodococcus spp.	0	5	10
Shinella spp.	0	2	0
Sphingomonas spp	0	2	1
Sphingopyxis spp.	0	1	3
Spirosoma spp.	0	1	0
Stenotrophomonas spp.	0	1	0
Variovorax spp.	1	5	1

- 135 colonies were indentified to the genus level (genera with only one colony identified are not included in table)
- Abundances of *Dechloromonas*, *Acidovorax*, and *Zoogloea* spp. in control sample (CT = 0) are consistent with previously determined microbial community structure of BAC biomass
- *Bosea* and *Rhodococcus* spp. are most resistant bacteria in the mixed microbial community
- Results agree with three-population model